AD-A024 803

737

ar Electromagnetic Pulse Simulation by Point Source Injection Techniques for Shielded and Unshielded Penetrations—by Robert F. Gray

Nuclear Electromagnetic Pulse Simulation by Point Source Injection Techniques for Shielded and Unshielded Penetrations

December 1975

THIS RESEARCH WAS SPONSORED BY THE DEFENSE NUCLEAR AGENCY
UNDER SUBTASK R99QAXEB075-43, WORK UNIT 41,
WORK UNIT TITLE "EMP PROGRAM"

RESEARCH
DEVELOPMENT
ENGINEERING

U.S. Army Materiel Command
HARRY DIAMOND LABORATORIES
Adelphi, Maryland 20783

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER HDL-TR-1737	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Nuclear Electromagnetic Pulse Simulation by Point Source Injection Techniques for Shielded and Unshielded Penetrations		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert F. Gray		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Harry Diamond Laboratories 2800 Powder Mill Road Adelphi, MD 20783		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program: 6.27.04.H Work Unit: 41
11. CONTROLLING OFFICE NAME AND ADDRESS Director Defense Nuclear Agency Washington, DC 20305		12. REPORT DATE December 1975
		13. NUMBER OF PAGES 56
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

HDL Project No.: E194E2 AMCMS Code: 6910002210917
This research was sponsored by the Defense Nuclear Agency under Subtask R99QAXEB075-43, Work Unit 41, Work Unit Title "EMP Program."

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Current injection
Cable drivers
EMP simulation
Shielded cables
Shielding effectiveness

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Nuclear electromagnetic pulse simulation by point source injection techniques were investigated for shielded and unshielded system penetrations. Circuit theory is applied to the unshielded case and a generalized injection system is suggested. To determine the relationship between point source current injection on the external shield of a cable and its response to free-field EMP excitation, general transmission line solutions were obtained in the frequency domain for each case. A numerical transform was used to obtain time domain waveforms of the external and internal currents. Both solutions were verified with experimental data collected on a braided shield coaxial cable that exhibited both types of reactive coupling (inductive and capacitive) through its shield. Shielding effectiveness transfer functions were experimentally obtained with a coaxial cable driver to determine the shield parameters. The two types of excitation were compared as a function of length and shield type indicating when single point source excitation became inadequate. Experimental results show the potential of a multiple source injection system for free-field simulation.

CONTENTS

FIGURES

1. INTRODUCTION

The overall objective of the program reported on here is to develop current injection technology for threat and lower-level system electromagnetic pulse (EMP) assessment. In general, a current injection system creates a transient current on a system penetration by means of a point source or sources coupled to the penetration either directly (resistive) or reactively (capacitance or inductive). This type of simulation is useful whenever other simulation techniques are inadequate or unrealizable from the standpoint of either peak amplitude or area of illumination.

One condition that must exist for this type of simulation to be valid is that in the event of an actual EMP, distinct points of entry excite sensitive circuits with induced signals that are due predominantly to electromagnetic responses of external conductors; consequently, it is assumed that interior electromagnetic fields within a system/subsystem enclosure do not contribute significantly to circuit upset or damage. If this assumption is not valid, it is still possible to obtain useful information from the direct-drive technique, but the data reduction becomes far more complex. Therefore, the discussion here is limited to when exterior coupling phenomena dominate the system response. Also, to accurately or adequately drive a system penetration, a greater understanding of the free-field coupling mechanisms is required than is necessary for free-field simulation. That is, before a system penetration can be driven, a description of the EMP coupled waveform and its distribution along the penetration must be obtained from either low-level free-field testing or analytical predictions.

In addition to these caveats regarding proper use of current injection, it is necessary also to demonstrate a relationship between the threat response of a system and that due to a current injection technique. To establish such a relationship, the system penetrations are divided into two cases, shielded and unshielded. A general approach for each of these cases is outlined, and then, because of the complexity of the problem, the shielded case is analyzed in more detail.

2. APPROACH

2.1 Unshielded Case

Typical examples of unshielded penetrations are incoming or outgoing ac power lines, deliberate antennas, and unshielded control or communication cables that are exterior to the system structure. In figure 1, the unshielded system penetration has an impedance Z_{in} looking into the system from points A and B and an impedance Z_{out} looking away from the system. If the impedances Z_{in} and Z_{out} are reasonably well behaved with respect to some reference conductor, G, and there is no significant coupling to the penetration further into the system, then the transient current, i(t), may be directly injected on the penetration using either a Thévenin's or Norton's equivalent source as shown in figure 2. For most unshielded cases, the Norton's equivalent should be

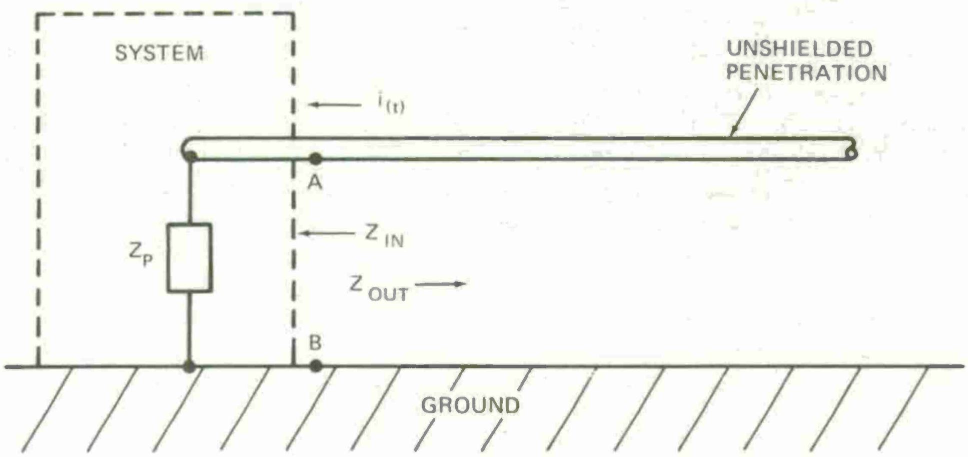


Figure 1. A system with an unshielded penetration.

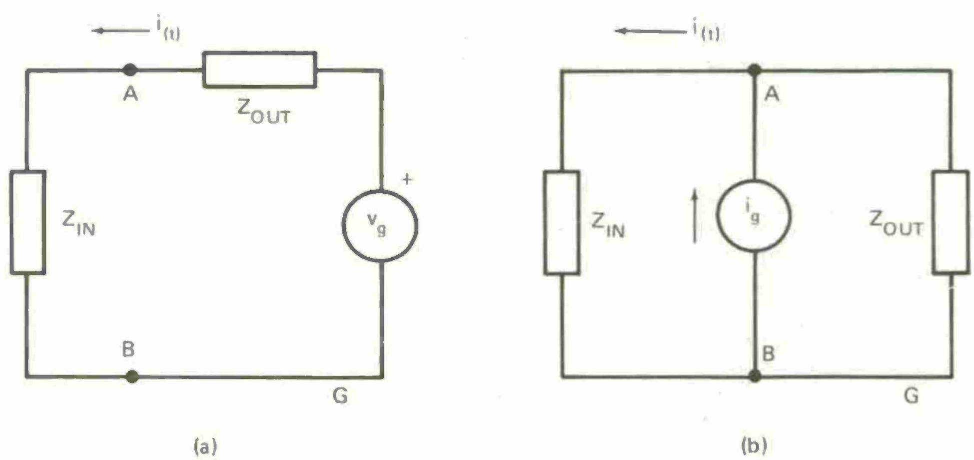


Figure 2. A Thévenin's (a) and Norton's (b) equivalent injection system.

used, because most transient high-voltage sources are an open circuit, except when discharging, and by definition, the Thévenin's voltage source, V_g, must be a short circuit when shut down. This open-circuit condition before and after discharge would unload the system at the penetration and possibly damage it. If, however, the load on the system is not critical, then a Thévenin's equivalent may be useful, because it offers a higher efficiency over a Norton equivalent source. In order not to load the system improperly, the current source, i_g, must have an internal impedance much greater than the parallel impedance of Z_{in} and Z_{out} for all frequencies of interest, so a larger source is required than for the Thévenin system. However, this inefficiency allows greater freedom in adjusting the source waveform, since a shaping impedance, Z_s, may be placed across the source without affecting the system because of the isolation impedance, Z_I, as shown in figure 3. The current source, i_g, of figure 2 is simulated in figure 3 by the voltage source, v_g, and the coupling impedances, Z_I and Z_s. Also, the use of a Norton source eliminates the need for physically altering the system, since it is necessary only to connect the source between points A and B.

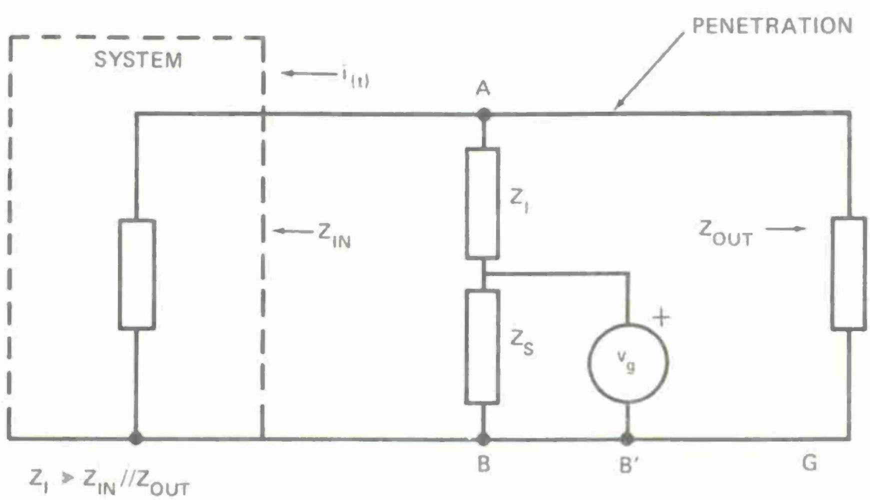


Figure 3. A current injection system for unshielded penetrations.

If no reference conductor is readily associated with the penetration, then it may still be possible to inject current on the penetration in one of two ways. As one way, a reference conductor could be added from the desired drive point to some ground point further into the system. However, care must be exercised in doing so, because it is possible to alter the system characteristics drastically (at least for the penetration of interest). Another, more preferable, technique involves inductively coupling the current with a ferrite core or similar transformer device, as shown in figure 4. The major advantage of this type of drive is that it is not physically connected to the system. This loose coupling, however, also makes the driver inefficient, and it is difficult to regulate the injected current waveshape.

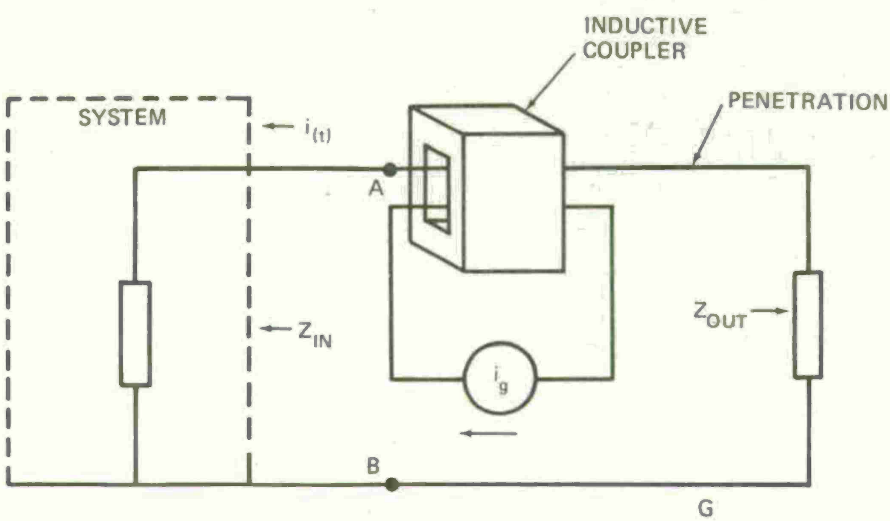


Figure 4. Inductively coupled injection system.

2.2 Shielded Case

The most common type of shielded penetration is a multiconductor cable with an external metallic shield or a standard coaxial cable. This type of penetration is analyzed here in the absence of terminal system/subsystem enclosures. Because of the physical size of most terminal enclosures, electromagnetic scattering by these obstacles and the resulting contributions to responses of interconnecting cables cannot be included in the transmission line approach used here. Furthermore, when the penetration to be driven is a shielded cable, it is usually necessary to inject current on the external shield, rather than the internal conductors, because either the internal response is not known or the number of internal conductors is too large to consider driving them. Threat-induced signals in terminations of internal conductors can be adequately simulated via point-source excitation of the external shield, but doing so is complex, because coupled internal signals depend on the distribution and propagation of the external driving current. Therefore, the objective of this study is to describe induced internal signals due to a distributed source and the corresponding signals due to a point source. Correlation of such signals shows the adequacy of a direct-drive technique in simulating free-field induced responses for at least this basic case and gives insight to its applicability to more complex systems.

Transmission line theory is used to define the currents and voltages of interest in both cases. This approach has some limitations in the free-field case, but an exact solution for the external current and voltage would probably not alter the results significantly.

Transmission line theory is briefly outlined below. Then a circuit parameter model of the external cable shield is presented, along with a technique for measuring the parameters. The shielded model and transmission-line theory is then used to obtain general solutions for the two cases of interest.

A transmission line has length ℓ with a series impedance $Z = R + j\omega L$ and shunt admittance $Y = G + j\omega C$ per unit length such that its characteristic impedance $K = (Z/Y)^{1/2} = [(R + j\omega L)/(G + j\omega C)]^{1/2}$ and its propagation constant $\Gamma = (ZY)^{1/2} = [(R + j\omega L)(G + j\omega C)]^{1/2} = \alpha + j\beta$. If this line is terminated in an impedance Z_1 at $X = 0$ and an impedance Z_2 at $X = \ell$ and the line is excited at a point $X = \xi$ by a series generator of zero impedance (fig. 5), then from Schelkunoff,[1] the current, I_1, and the voltage, V_1, at any point along the line is

$$
\begin{aligned}
I_1(x,\xi) &= [K \cosh \Gamma x + Z_1 \sinh \Gamma x] \times \\
&\quad [K \cosh \Gamma(\ell - \xi) + Z_2 \sinh \Gamma(\ell - \xi)]/D, \; x < \xi \\
&= [K \cosh \Gamma\xi + Z_1 \sinh \Gamma\xi] \times \\
&\quad [K \cosh \Gamma(\ell - x) + Z_2 \sinh \Gamma(\ell - x)]/D, \; x > \xi \\
V_1(x,\xi) &= -K[K \sinh \Gamma x + Z_1 \cosh \Gamma x] \times \\
&\quad [K \cosh \Gamma(\ell - \xi) + Z_2 \sinh \Gamma(\ell - \xi)]/D, \; x < \xi \\
&= K[K \cosh \Gamma\xi + Z_1 \sinh \Gamma\xi] \times \\
&\quad [K \sinh \Gamma(\ell - x) + Z_2 \cosh \Gamma(\ell - x)]/D, \; x > \xi
\end{aligned}
\qquad (1)
$$

[1] *S. A. Schelkunoff, Electromagnetic Waves, D. Van Nostrand Co., New York (1943).*

where

$$D = K\left[(K^2 + Z_1 Z_2)\sinh \Gamma\ell + K(Z_2 + Z_1)\cosh \Gamma\ell\right].$$

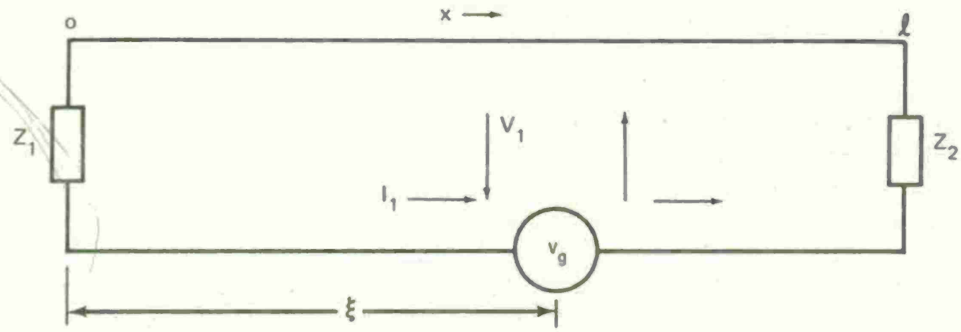


Figure 5. A transmission line excited by a series generator of zero impedance.

Similarly, if the line is excited by a shunt generator of infinite impedance, as in figure 6, the current, I_2, and the voltage, V_2, at any point along the line is given by

$$\begin{aligned}
I_2(x,\xi) &= K[K\cosh \Gamma x + Z_1 \sinh \Gamma x] \times \\
&\qquad [K\sinh \Gamma(\ell - \xi) + Z_2\cosh \Gamma(\ell - \xi)]/D, \; x < \xi \\
&= -K[K\sinh \Gamma\xi + Z_1\cosh \Gamma\xi] \times \\
&\qquad [K\cosh \Gamma(\ell - x) + Z_2\sinh \Gamma(\ell - x)]/D, \; x > \xi \\
V_2(x,\xi) &= -K^2[K\sinh \Gamma x + Z_1\cosh \Gamma x] \times \\
&\qquad [K\sinh \Gamma(\ell - \xi) + Z_2\cosh \Gamma(\ell - \xi)]/D, \; x < \xi \\
&= -K^2[K\sinh \Gamma\xi + Z_1\cosh \Gamma\xi] \times \\
&\qquad [K\sinh \Gamma(\ell - x) + Z_2\cosh \Gamma(\ell - x)]/D, \; x > \xi.
\end{aligned} \tag{2}$$

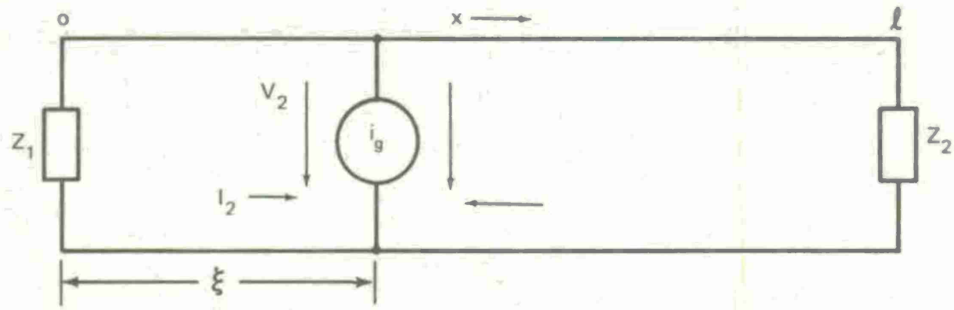


Figure 6. A transmission line excited by a shunt generator of infinite impedance.

These solutions for the discrete case can be used to determine the response due to a distributed excitation by integrating over the source region, as shown in equation (3).

$$I(x) = \int_{x_2}^{x_1} E(\xi) I_1(x,\xi)\, d\xi + \int_{x_2}^{x_1} J(\xi) I_2(x,\xi)\, d\xi$$

$$V(x) = \int_{x_2}^{x_1} E(\xi) V_1(x,\xi)\, d\xi + \int_{x_2}^{x_1} J(\xi) V_2(x,\xi)\, d\xi \quad (3)$$

where $E(\xi)$ is a series electromotive force per unit length and $J(\xi)$ is a shunt current per unit length distributed over the interval x_1, x_2. These integrals are used with the following models to define the responses for each case.

2.3 Cable Shield Model

Consider a conductor of radius r_a with a single coaxial shield of thickness t and inside radius r_b, as shown in figure 7.

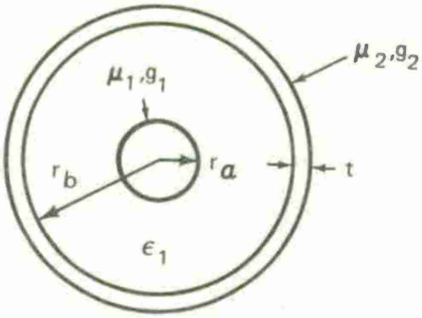


Figure 7. A conductor with a coaxial shield of thickness t.

The transfer impedance of a solid shield is given by Shelkunoff[2] to be $R_s = \eta/2\pi \left[r_b\left(r_b + t\right)\right]^{\frac{1}{2}} \sinh \sigma t$, where $\eta = j\omega\mu_2/\sigma$, $\sigma = (j\omega\mu_2 g_2)^{\frac{1}{2}}$, $\omega = 2\pi f$, f is the frequency, and g_2 and μ_2 are the conductivity and permeability of the shield, respectively.

A braided shield has two additional transfer parameters that have to be combined with the transfer impedance, R_s, given above. The longitudinal transfer impedance, Z_T, for a general cable is

$$Z_T = R_s + j\omega L_s$$

where L_s is the inductance/meter length of the shield. The lateral transfer admittance, Y_L, is

$$Y_L = j\omega C_H$$

where C_H is the capacitance/meter length between the inner conductor and an external reference conductor other than the shield. The assumed lossless dielectrics involved (inside and outside the shield) account for the purely reactive lateral transfer admittance. The parameters needed to calculate the solid shield transfer impedance, R_s, are usually

[2] *S. A. Schelkunoff, The Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields, Bell System Technical J. 13 (October 1934).*

well defined, but it is not possible to accurately calculate the inductive, L_s, and capacitive, C_H, terms needed for braided shields. Therefore, it is necessary to determine these two parameters experimentally.

A current, i_s, on the outside of the shield creates a distributed series electromotive force,

$$E(\xi) = Z_T i_s(\xi) = \left(R_s + j\omega L_s\right) i_s(\xi),$$

which excites the inner conductor according to equations (1) to (3). Similarly, any external voltage, $V_s(\xi)$, appearing between the cable shield and some reference conductor behaves as a shunt current source, $J(\xi)$, with the relationship

$$J(\xi) = Y_L V_s(\xi) = j\omega C_H V_s(\xi) \ .$$

The external voltages and currents need to be defined. Since the cable driver technique uses a point source at some point along the cable, equations (1) and (2) give the external voltage and current directly for any type of source. The coaxial cable driver to be considered has a point voltage source, V_s, at one end of the line $(x = 0)$. Therefore, the current, $i_s(x)$, and voltage, $v_s(x)$, along the line are

$$i_s(x) = V_s K_1 [K_1 \cosh \Gamma_1(\ell - x) + Z_2 \sinh \Gamma_1(\ell - x)] / D_1$$

$$v_s(x) = V_s K_1^2 [K_1 \sinh \Gamma_1(\ell - x) + Z_2 \cosh \Gamma_1(\ell - x)] / D_1 \qquad (4)$$

where the subscript is added to K, Γ, and D to differentiate between the external (1) and internal (2) lines.

For a distributed excitation, the integrals in equation (3) must be used to define the external voltage and current along the line. Equivalent series voltage and shunt current sources are defined by use of the incident electric and magnetic fields. Solutions for the internal current in both types of excitation may then be obtained by use of the external voltages and currents and the source models defined above.

3. COAXIAL CABLE DRIVER

3.1 Transmission Line Solution for Internal Current

The coaxial cable driver may be modeled with two separate transmission lines (fig. 8). Line ABDC is made up of the outside shell of the driver and the external cable shield. Line ABDC has a characteristic impedance of K_1 and a propagation constant of

$$\Gamma_1 = \alpha_1 + j\beta_1.$$

Line BDFE is made up of the external shield and the inner conductors and has a characteristic impedance of K_2 and a propagation constant of

$$\Gamma_2 = \alpha_2 + j\beta_2.$$

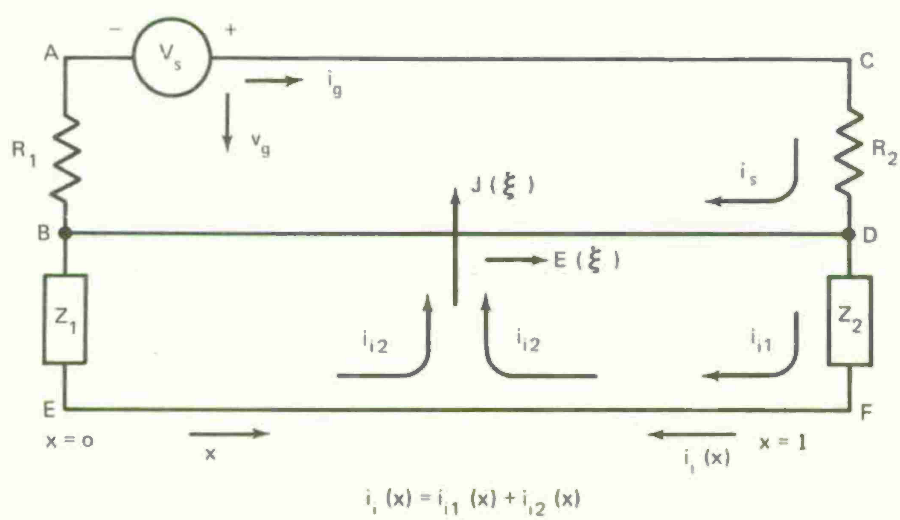


Figure 8. Circuit model of a coaxial cable driver.

V_s is the impressed source voltage, and i_g and v_g are the external transmission line current and voltage caused by V_s. $E(\xi)$ and $J(\xi)$ are distributed series electromagnetic field and shunt current sources causing internal currents i_{i1} and i_{i2}, respectively. The distributed electromagnetic field, $E(\xi)$, is produced by the sheath current, i_s, flowing on the shield, which has a transfer resistance, R_s (Ω/M), and braid inductance, L_s (h/M), as defined earlier. Therefore,

$$E(\xi) = -i_s(\xi)\left(R_s + j\omega L_s\right) = -Z_T i_s(\xi) = -Z_T\left(-i_g + i_i\right). \qquad (5)$$

But since the internal coupling is small,

$$i_s(\xi) \approx -i_g(\xi),$$

$$\therefore E(\xi) \approx Z_T i_g(\xi) .$$

The distributed shunt current source, $J(\xi)$, represents the coupling of the propagated driver voltage, v_g, through the holes in the braided shield as suggested by Frankel,[3] Vance,[4] and others. The coupling through the holes in the braid has the characteristics of capacitance C_H (per unit length) between the inner conductors and the external driver shell:

$$\therefore J(\xi) = -j\omega C_H v_g(\xi). \qquad (6)$$

---

[3]*S. Frankel, Terminal Response of Braided-Shield Cables to External Monochromatic Electromagnetic Fields, Harry Diamond Laboratories TR-1602 (August 1972).*

[4]*E. F. Vance, Comparison of Electric and Magnetic Coupling through Braided-Wire Shields, TM 18, Air Force Weapons Laboratory, Kirtland Air Force Base, Albuquerque, NM (February 1972).*

This is an approximation, because the shunt generator is really a function of the difference between the propagated driver voltage, v_g, and the internal cable voltage, v_i, but the coupling is small, so that

$$v_g - v_i \approx v_g \, .$$

$$i_s(\xi) \approx -i_g(\xi) = -\frac{V_s\left[K_1 \cosh \Gamma_1(\ell - \xi) + R_2 \sinh \Gamma_1(\ell - \xi)\right]}{\left(K_1^2 + R_1R_2\right) \sinh \Gamma_1\ell + K_1\left(R_1 + R_2\right) \cosh \Gamma_1\ell}, \quad (7)$$

$$v_g(\xi) = \frac{K_1V_s\left[K_1 \sinh \Gamma_1(\ell - \xi) + R_2 \cosh \Gamma_1(\ell - \xi)\right]}{\left(K_1^2 + R_1R_2\right) \sinh \Gamma_1\ell + K_1\left(R_1 + R_2\right) \cosh \Gamma_1\ell}, \quad (8)$$

$$\begin{aligned} i_{i_1}(x) &= -\int_0^\ell E(\xi)I_1(x,\xi)\, d\xi \\ &= -\frac{V_sZ_T}{K_2D_1D_2}\Big\{\left[K_2 \cosh \Gamma_2(\ell - x) + Z_2 \sinh \Gamma_2(\ell - x)\right] \\ &\quad \cdot\int_0^x A_1(\xi)B_1(\xi)\, d\xi \qquad (9) \\ &\quad + \left[K_2 \cosh \Gamma_2 x + Z_1 \sinh \Gamma_2 x\right] \int_x^\ell A_1(\xi)B_2(\xi)\, d\xi\Big\}, \end{aligned}$$

where

$$A_1(\xi) = K_1 \cosh \Gamma_1(\ell - \xi) + R_2 \sinh \Gamma_1(\ell - \xi)$$

$$B_1(\xi) = K_2 \cosh \Gamma_2\xi + Z_1 \sinh \Gamma_2\xi$$

$$B_2(\xi) = K_2 \cosh \Gamma_2(\ell - \xi) + Z_2 \sinh \Gamma_2(\ell - \xi)$$

$$D_1 = \left(K_1^2 + R_1R_2\right) \sinh \Gamma_1\ell + K_1\left(R_1 + R_2\right) \cosh \Gamma_1\ell$$

$$D_2 = \left(K_2^2 + Z_1Z_2\right) \sinh \Gamma_2\ell + K_2\left(Z_1 + Z_2\right) \cosh \Gamma_2\ell .$$

$$i_{i_2}(x) = \int_o^\ell J(\xi)I_2(x,\xi)\, d\xi = -j\omega C_H \int_o^\ell v_g(\xi)I_2(x,\xi)\, d\xi \tag{10}$$

$$= \frac{j\omega C_H K_1 V_s}{D_1D_2} \Bigg[\Big\{K_2 \cosh \Gamma_2(\ell - x) + Z_2 \sinh \Gamma_2(\ell - x)\Big\}$$

$$\cdot\int_o^x A_2(\xi)C_1(\xi)\, d\xi - \Big\{K_2 \cosh \Gamma_2x + Z_1 \sinh \Gamma_2x\Big\}$$

$$\cdot\int_x^\ell A_2(\xi)C_2(\xi)\, d\xi\Bigg],$$

where

$$A_2(\xi) = K_1 \sinh \Gamma_1(\ell - \xi) + R_2 \cosh \Gamma_1(\ell - \xi)$$

$$C_1(\xi) = K_2 \sinh \Gamma_2\xi + Z_1 \cosh \Gamma_2\xi$$

$$C_2(\xi) = K_2 \sinh \Gamma_2(\ell - \xi) + Z_2 \cosh \Gamma_2(\ell - \xi) .$$

After the integration and collection of terms, the general solution for the internal current at $x = \ell$ is found to be

$$i_i(\ell) = i_{i_1}(\ell) + i_{i_2}(\ell)$$

$$= \frac{V_s Z_T}{2D_1D_2}\left[K_2P \left\{\frac{\sinh \Gamma_s\ell}{\Gamma_s} + \frac{\sinh \Gamma_D\ell}{\Gamma_D}\right\}\right.$$

$$+ K_2 Q \left\{ \frac{1 - \cosh \Gamma_s \ell}{\Gamma_s} + \frac{1 - \cosh \Gamma_D \ell}{\Gamma_D} \right\}$$

$$- Z_1 P \left\{ \frac{1 - \cosh \Gamma_s \ell}{\Gamma_s} - \frac{1 - \cosh \Gamma_D \ell}{\Gamma_D} \right\}$$

$$- Z_1 Q \left\{ \frac{\sinh \Gamma_s \ell}{\Gamma_s} - \frac{\sinh \Gamma_D \ell}{\Gamma_D} \right\} \Bigg] \tag{11}$$

$$+ \frac{j\omega C_H K_1 V_s K_2}{2 D_1 D_2} \Bigg[Z_1 Q \left\{ \frac{\sinh \Gamma_s \ell}{\Gamma_s} + \frac{\sinh \Gamma_D \ell}{\Gamma_D} \right\}$$

$$+ Z_1 P \left\{ \frac{1 - \cosh \Gamma_s \ell}{\Gamma_s} + \frac{1 - \cosh \Gamma_D \ell}{\Gamma_D} \right\}$$

$$- K_2 Q \left\{ \frac{1 - \cosh \Gamma_s \ell}{\Gamma_s} - \frac{1 - \cosh \Gamma_D \ell}{\Gamma_D} \right\}$$

$$- K_2 P \left\{ \frac{\sinh \Gamma_s \ell}{\Gamma_s} - \frac{\sinh \Gamma_D \ell}{\Gamma_D} \right\} \Bigg]$$

where

$$P = K_1 \cosh \Gamma_1 \ell + R_2 \sinh \Gamma_1 \ell$$

$$Q = K_1 \sinh \Gamma_1 \ell + R_2 \cosh \Gamma_1 \ell$$

$$\Gamma_s = \Gamma_1 + \Gamma_2$$

$$\Gamma_D = \Gamma_1 - \Gamma_2 \, .$$

The shielding effectiveness transfer function of a cable is defined as the ratio of the internal current at $x = \ell$ to the external current at $x = \ell$ with the external line terminated in its characteristic impedance at $x = \ell$ $(R_2 = K_1)$. This definition is useful in determining the relative shielding quality of different cable shields by use of experimental techniques to obtain the transfer functions.[5] Also, some insight into a testing technique to determine the reactive shield parameters may be gained by examining the general solution for the transfer function given in equation (12).

General solution at $x = \ell$ and $K_1 = R_2$:

$$\frac{i_i(\ell)}{i_s(\ell)} =$$

$$\frac{\left[Z_T + j\omega C_H K_2 K_1\right]\left[\frac{(K_2 + Z_1)\left(e^{\Gamma_1 \ell} - e^{\Gamma_2 \ell}\right)}{(\Gamma_1 - \Gamma_2)\ell}\right]\ell + \left[Z_T - j\omega C_H K_2 K_1\right]\left[\frac{(K_2 - Z_1)\left(e^{\Gamma_1 \ell} - e^{-\Gamma_2 \ell}\right)}{(\Gamma_1 + \Gamma_2)\ell}\right]\ell}{-2\left[\left(K_2^2 + Z_1 Z_2\right) \sinh \Gamma_2 \ell + K_2(Z_1 + Z_2) \cosh \Gamma_2 \ell\right]} . \tag{12}$$

If the line length, ℓ, is very small compared to the wavelength, $\lambda_i = 2\pi/\beta_i$, so that $\Gamma_i \ell \doteq 0$, then

$$\sinh \Gamma_2 \ell \to 0$$

$$\cosh \Gamma_2 \ell \to 1$$

$$\frac{e^{\Gamma_1 \ell} - e^{\Gamma_2 \ell}}{\left(\Gamma_1 - \Gamma_2\right) \ell} \to 1$$

$$\frac{e^{\Gamma_1 \ell} - e^{-\Gamma_2 \ell}}{\left(\Gamma_1 + \Gamma_2\right) \ell} \to 1$$

---

[5] *R. Gray and R. McCue, Shielding Effectiveness Tests on Typical Access Facility Telephone Cables, Harry Diamond Laboratories TM-73-3 (July 1973).*

and equation (12) simplifies to

$$\frac{i_i(\ell)}{i_s(\ell)} = - \frac{\left(Z_T + j\omega C_H K_1 Z_1\right)\ell}{Z_1 + Z_2} \quad . \tag{13}$$

The two coupling parameters may be separated by proper choice of the internal terminations Z_1 and Z_2. If Z_1 is set equal to zero, then the transfer function becomes simply

$$\frac{i_i(\ell)}{i_s(\ell)} = - \frac{Z_T\ell}{Z_2} = - \frac{\left(R_s + j\omega L_s\right)\ell}{Z_2} \tag{14}$$

which allows L_s to be determined, since R_s is well defined, as stated earlier. If the line is match terminated at both ends so that

$$Z_1 = Z_2 = K_2 \ ,$$

then the capacitive parameter, C_H, also may be determined experimentally:

$$\frac{i_i(\ell)}{i_s(\ell)} = - \frac{\left(Z_T + j\omega C_H K_1 K_2\right)}{2K_2} \ . \tag{15}$$

3.2 Experimental Verification of General Solution

To verify the general solution, shielding effectiveness tests were conducted on a cable with a braided shield that exhibited both types of reactive coupling. A 1-m length of the cable was used to determine the coupling parameters, and a 30-m length was driven for comparison with a calculated response. This cable had 25 internal conductors, some with separate inner shields, and was designed for the Pershing Missile System. The internal conductors and their shields were soldered together at each end of the test cables, to simulate a coaxial cable as required by equation (12). The external braid of this cable was woven at an angle of 30 deg from the axis and had an optical coverage of 70 percent. The dc resistance of the inner bundle and the external shield was measured to determine the actual conductivity of these nonsolid conductors. The characteristic impedances K_1 and K_2 and the velocities of propagation of each line were determined with time-domain reflectometry. Time-domain data were collected with a wide bandwidth oscilloscope, and frequency spectra of the two currents were obtained by use of a spectrum analyzer and a repetitively pulsing, capacitive discharge source. The frequency spectra were reduced to the desired transfer functions by a Hewlett-Packard 9830 calculator with a digitizer and plotter. The 1-m cable transfer functions are given in figure 9 (p 22). By these curves, the external braid inductance, L_S, was found to be 8.15×10^{-10} H/m, and the capacitive coupling parameter, C_H, was calculated to be -4.5×10^{-13} F/m. The negative capacitance indicates an error in the original choice of current directions.

The experimental and calculated cable-driver responses of a 100-ft length of the same cable are given in figures 10 and 11 (p 23,24). The minimum occurring around 0.5 MHz in the 100-ft transfer function is due to an interaction between the inductive and capacitive coupling terms and does not occur in the calculated result if only an inductive shield representation is used. This effect indicates the importance of determining both types of reactive coupling. The nearly rectangular pulse at the beginning of the time history is due to the difference in propagation velocities on the inside and outside of the cable. The correlation between the experimental and calculated response is believed to be sufficient to allow the use of calculated responses in comparing point source excitation with free-field responses.

4. FREE-FIELD SOLUTION

4.1 Transmission Line Solution

A conductor of length ℓ and radius a is over a real earth at some height, h, which is illuminated by a horizontally polarized plane wave, as shown in figure 12.

The resultant fields (incident plus reflected) in the xy plane are found by Klebers[6] to be

$$E_{xy(\omega)} = E_{o(\omega)} \left[1 + R_H e^{-jk\Delta r}\right] \tag{16}$$

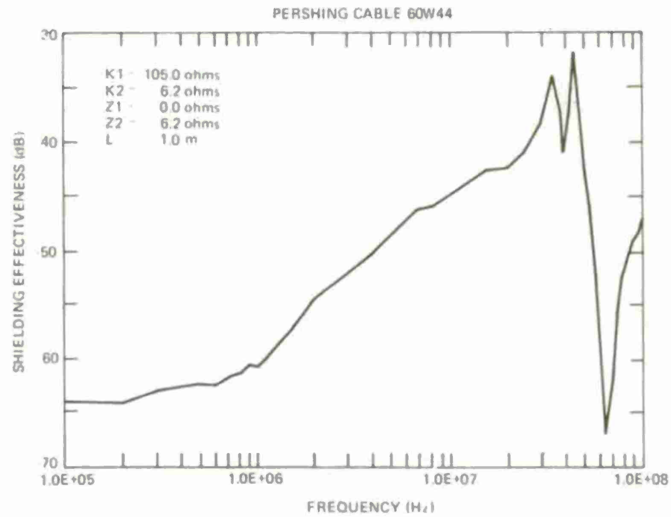
$$H_{xy(\omega)} = E_{o(\omega)} \left[1 - R_H e^{-jk\Delta r}\right] \sin(\psi)/Z_o$$

[6] *J. Klebers, Time Domain Analysis of the Electromagnetic Field in the Presence of a Finitely Conducting Surface, MERDC (29 January 1969).*

where

$$R_H \approx -1 + \frac{2 \sin(\psi)}{\left(\varepsilon_r - j\sigma_g/\omega\varepsilon_o\right)^{\frac{1}{2}}} \quad = \text{approximate reflection coefficient}$$

$k = \omega/c$, $\Delta r = 2h \sin(\psi)$, ψ is the angle of incidence, Z_o is the free space impedance (377 ohms), and $\varepsilon_r = \varepsilon_g/\varepsilon_o$.



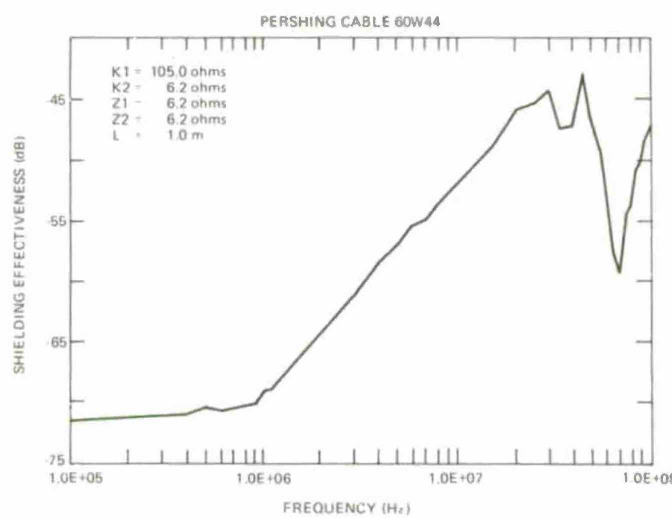


Figure 9. Shielding effectiveness curves for shield parameter definition.

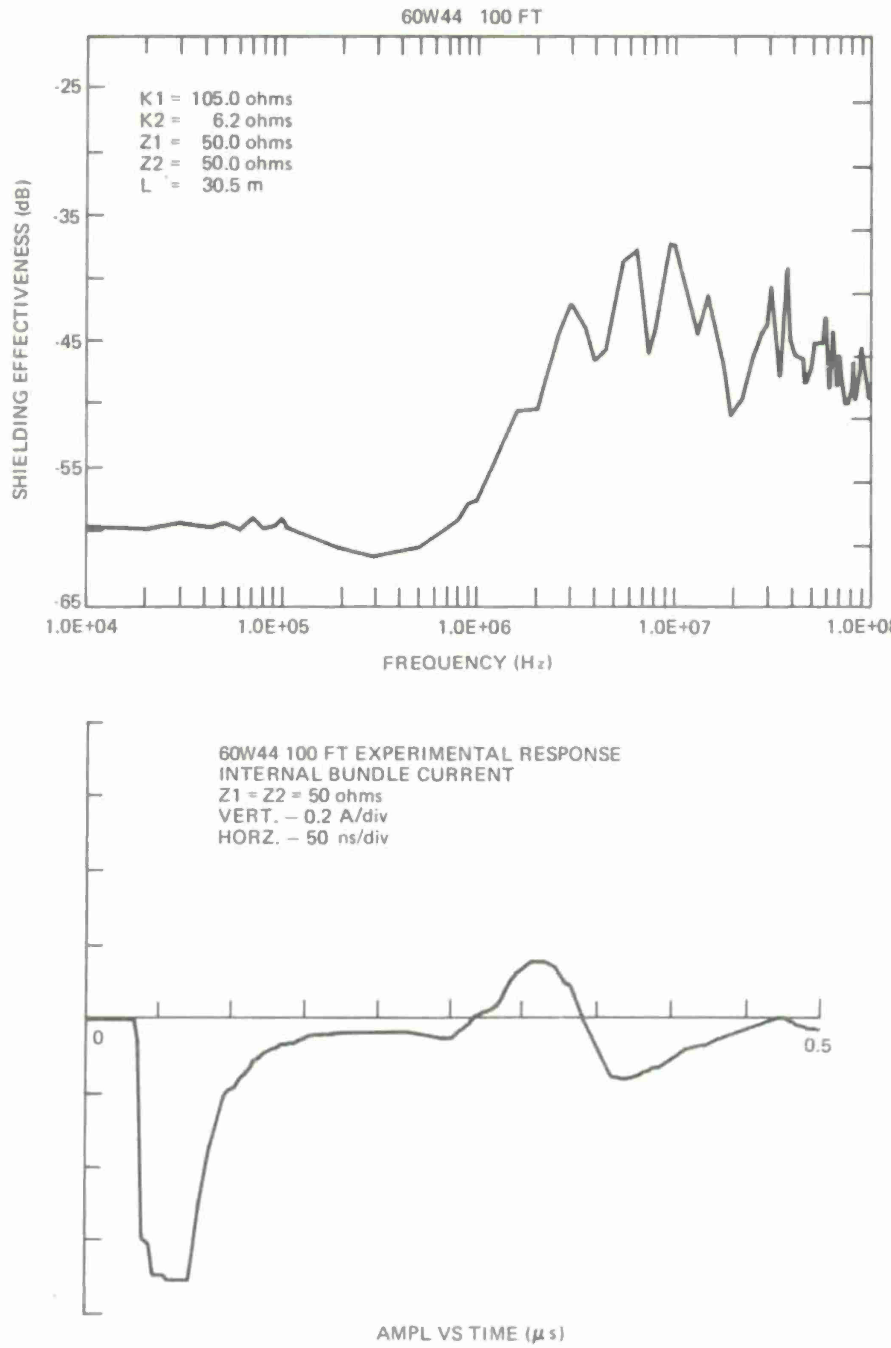
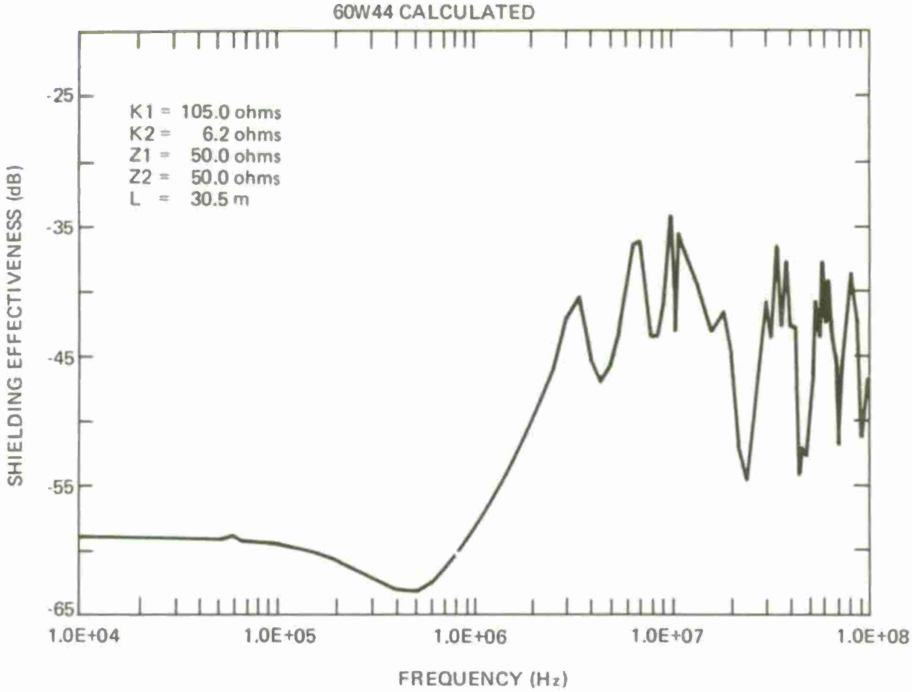


Figure 10. Experimental response of a 100-ft cable due to coaxial driver excitation.



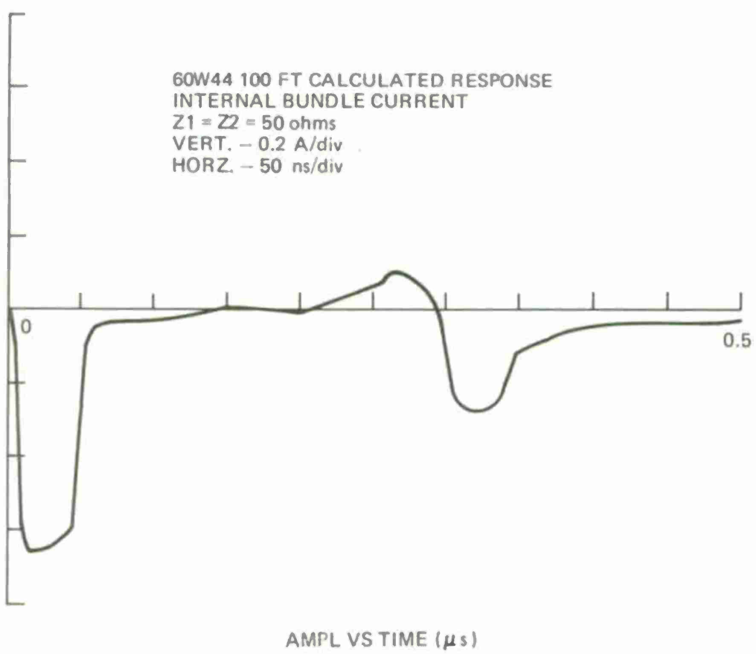


Figure 11. Calculated response of a 100-ft cable due to coaxial driver excitation.

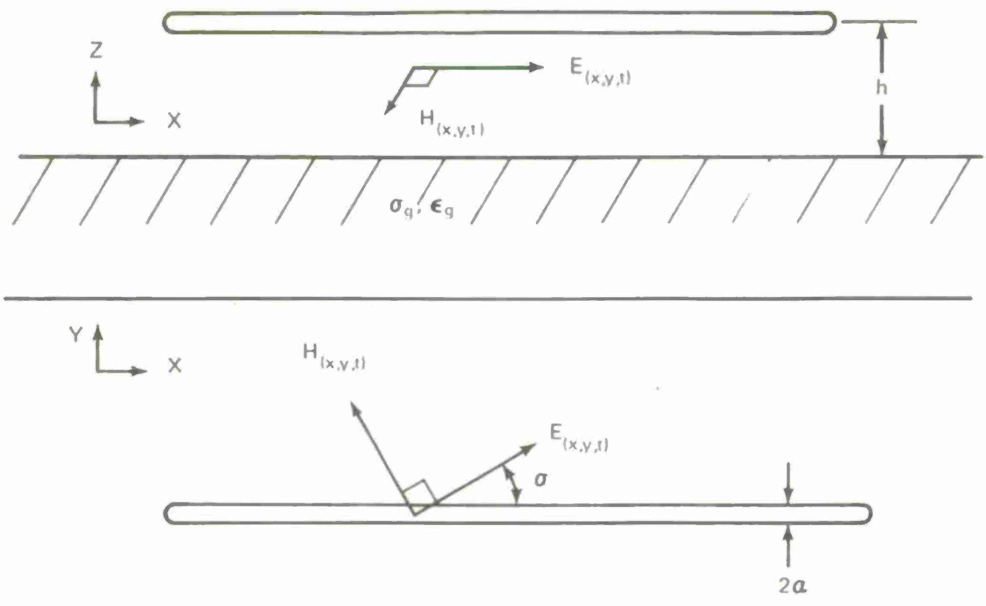


Figure 12. A conductor illuminated by a horizontally polarized wave.

The effective driving fields are the electric field, E_p, parallel to the conductor and the magnetic field, H_n, perpendicular to the conductor. In the time domain, these fields are

$$E_p(x,t) = E(t-t') \cos(\theta)\ U(t-t')$$
$$H_n(x,t) = H(t-t') \cos(\theta)\ U(t-t') \tag{17}$$

where $t' = (x/c) \sin(\theta) \cos(\psi)$ is the time delay along the line due to the wave propagating with the speed of light, c. Transformed into the frequency domain,

$$E_p(x,\omega) = E_{xy}(\omega) \cos(\theta)\, e^{-j\left[(x/c) \sin(\theta) \cos(\psi)\right]\omega}$$

$$H_n(x,\omega) = H_{xy}(\omega) \cos(\theta)\, e^{-j\left[(x/c) \sin(\theta) \cos(\psi)\right]\omega} . \tag{18}$$

The perpendicular magnetic field, H_n, may be converted to an equivalent parallel electric field by means of a coupling impedance, $Z_c = j\omega L_c$, where L_c is the inductive field coupling parameter defined by Frankel[3] to be

$$L_c = \mu_o a \left((h/a)^2 - 1\right)^{\frac{1}{2}} ,$$

for a single wire over ground. Therefore, the total equivalent electric field, E_T, driving the conductor is

$$E_T(x,\omega) = E_p(x,\omega) + j\omega L_c H_n(x,\omega)$$

$$= \left[\left(E_p(\omega) + j\omega L_c H_n(\omega)\right)\right] \cos\theta\, e^{-j\frac{\omega}{c}x \sin(\theta) \cos(\psi)}$$

$$= E_T(\omega) e^{-j\frac{\omega}{c}x \sin(\theta) \cos(\psi)} \tag{19}$$

and this field may be used to determine the current and voltage along the line by use of equation (3).

---

[3]*S. Frankel, Terminal Response of Braided-Shield Cables to External Monochromatic Electromagnetic Fields, Harry Diamond Laboratories TR-1602 (August 1972).*

The earth can be assumed to be a reasonable approximation of an infinitely conducting surface such that the conductor and its image in the earth may be treated as a two-wire transmission line. This line has an impedance

$$K_1 = 0.5(Z/Y)^{\frac{1}{2}} = 0.5\left((R + j\omega L)/j\omega C\right)^{\frac{1}{2}},$$

terminations Z_1 and Z_2 at $x = 0$ and ℓ, respectively, and a velocity of propagation, v_1. The variation in propagation velocity of the cable with height aboveground was empirically determined by measuring the current at the center of a 40-ft unterminated cable for various heights above- and belowground due to illumination by the Biconic Simulator at the Woodbridge Research Facility of the Harry Diamond Laboratories. This simulator consists of a dipole antenna that is driven in the time domain by a Marx generator at a biconical center feed section. A radiating dipole antenna is formed by extending cylindrical arms from the bicones. The experimentally determined propagation velocities are shown in figure 13. This curve was represented by the function

$$v_1 = 0.5C\left(1 + 1/\left(\varepsilon_r\right)^{\frac{1}{2}} + \left(1 - 1/\left(\varepsilon_r\right)^{\frac{1}{2}}\right) \tanh\ (4.4h - 0.449)\right)$$

and is also presented in figure 13 (p 29). This representation makes the propagation velocity frequency independent. However, this is not an unreasonable approximation when the cable is aboveground, since losses have only a second-order effect on the velocity

$$\left(v = v_o\left[1 - \frac{1}{8\omega^2}\left(\frac{R}{L} - \frac{G}{C}\right)^2\right]\right).^{1}$$

The external current along the conductor is found to be

$$i_s(x,\omega) = \frac{E(\omega)M(x)}{D_1}$$

$$\cdot \int_o^x \left[K_1 \cosh \Gamma_1\xi + Z_2 \sinh \Gamma_1\xi\right] e^{-j\left(\frac{\omega \sin\ (\theta)\ \cos\ (\psi)}{c}\right)\xi}\, d\xi$$

$$+ \frac{E(\omega)N(x)}{D_1}$$

$$\cdot \int_x^{\ell} \left[K_1 \cosh \Gamma_1(\ell - \xi) + Z_1 \sinh \Gamma_1(\ell - \xi)\right] e^{-j\left(\frac{\omega \sin(\theta) \cos(\psi)}{c}\right)\xi} d\xi$$

$$= \frac{E(\omega)}{2D_1} \left[\left\{K_1 \cosh \Gamma_1(\ell - x) + Z_2 \sinh \Gamma_1(\ell - x)\right\}\right.$$

$$\left\{\frac{(K_1 - Z_1)\left(1 - e^{-(\Gamma_1 + j\beta')x}\right)}{\Gamma_1 + j\beta'} - \frac{(K_1 + Z_1)\left(1 - e^{(\Gamma_1 - j\beta')x}\right)}{\Gamma_1 - j\beta'}\right\} \tag{20}$$

$$+ \varepsilon^{-j\beta'\ell}\left\{K_1 \cosh \Gamma_1 x + Z_1 \sinh \Gamma_1 x\right\}$$

$$\cdot \left.\left\{\frac{(K_1 - Z_2)\left(1 - e^{(\Gamma_1 - j\beta')(x - \ell)}\right)}{\Gamma_1 - j\beta'} - \frac{(K_1 + Z_2)\left(1 - e^{-(\Gamma_1 + j\beta')(x - \ell)}\right)}{\Gamma_1 + j\beta'}\right\}\right]$$

where

$$M(x) = K_1 \cosh \Gamma_1(\ell - x) + Z_2 \sinh \Gamma_1(\ell - x)$$

$$N(x) = K_1 \cosh \Gamma_1 x + Z_1 \sinh \Gamma_1 x$$

$$D_1 = K_1\left[\left(K_1^2 + Z_1 Z_2\right) \sinh \Gamma_1 \ell + K_1(Z_1 + Z_2) \cosh \Gamma_1 \ell\right]$$

$$\beta' = \omega \sin(\theta) \cos(\psi)/c.$$

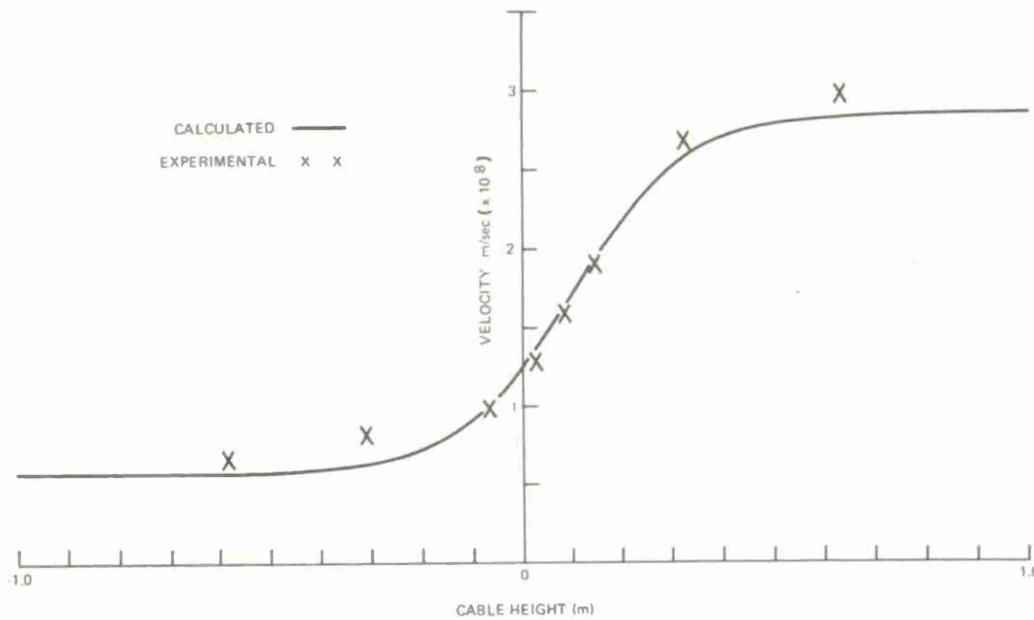


Figure 13. Propagation velocity as a function of cable height.

A similar solution is obtained for the external voltage, $v_s(x,\omega)$. The internal current is then found by use of the external voltage and current solutions and the following integration:

$$i_i(x,\omega) = \int_o^{\ell} \left[Z_T i_s(\xi,\omega) I_1(x,\xi) - j\omega C_H v_s(\xi,\omega) I_2(x,\xi) \right] d\xi \qquad (21)$$

where $I_1(x,\xi)$ and $I_2(x,\xi)$ have been defined earlier. The solutions for the internal currents are not presented here because of their bulk. However, they have been programmed (FREFLD) along with the external current solution and field definition for a threatlike incident field (double exponential representation) to run on a PDP 11/40 computer. Time-domain solutions are obtained with the same numerical inverse transform as used for the coaxial driver solution.

4.2 Experimental Verification

To validate the results of the program FREFLD, calculations were made for several cable conditions for which experimental results existed. Most of the experimental data were collected by use of the Biconic antenna. Many of the differences between theory and experiment seem to be attributable to the fact that the calculations were made with an idealized double exponential incident field, which is, at best, a rough approximation of the field radiated by the Biconic Simulator.

The external current at the center of a 40-ft cable was calculated for two different heights aboveground. The results along with the experimental data are given in figures 14 and 15. Although the calculated waveforms do not exactly duplicate the measured responses, they do exhibit the same general trends, such as the increase in the effective length of the cable and attenuation as the cable is closer to the earth.

The next set of data (fig. 16) demonstrates the effect of the angle of rotation, θ, between the incident electric field and the axis of the cable. These calculations were made for a 1500-ft cable that was terminated in a slightly inductive short to earth at each end. Internal current was calculated by use of a solid shield found to be representative of that used in telephone systems.[5] The internal termination at $x = 0$ was a matched impedance ($Z_3 = K_2$), and at $x = \ell$, the calculation point, the inner bundle was shorted to the shield. The external current peak amplitude increased considerably, whereas its duration decreased (due to a shortening of its electrical length) as the angle of rotation varied from broadside to near end-fire illumination. This effect was found in scale-model measurements for similar conditions. The solid-line graph in figure 17 plots the measured initial current peaks relative to the peak at broadside incidence. Also shown (with x's) are the relative calculated peak amplitudes, including some additional angles not shown earlier. The internal current peak increases only slightly and then decreases with increasing angle of rotation.

A set of field measurements was made on the same 100-ft cable that was used to validate the coaxial driver work. The Biconic antenna was used to illuminate the cable with a 0-deg angle of rotation (θ = 0 deg) and a 7-deg incidence with the earth (ψ = 7 deg). The cable was supported at 1 m aboveground, and the measurements were made with both open- and short-circuit terminations at each end:

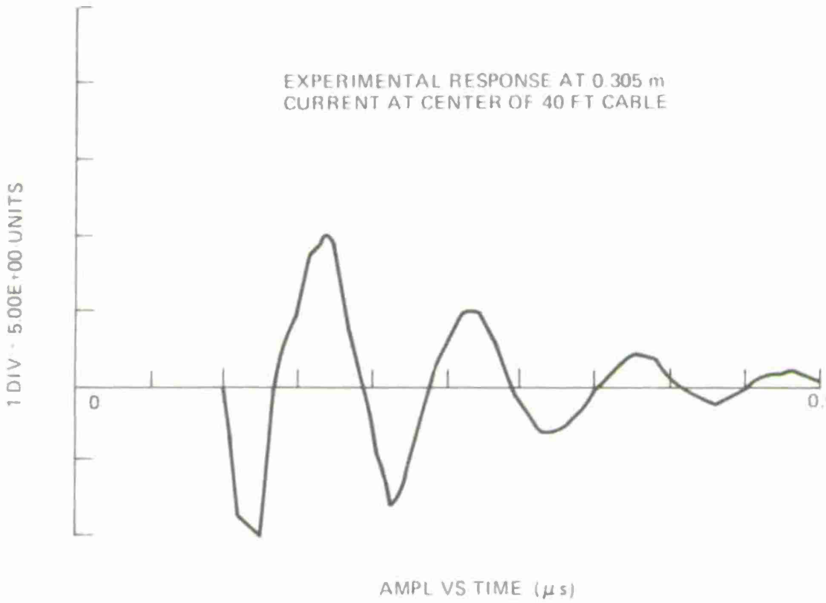
$$Z_1 = Z_2 = 0 \text{ and } Z_1 = Z_2 = \infty \ .$$

The external current was measured at the center of the cable, and the internal current was measured with both ends matched terminated:

$$Z_3 = Z_4 = K_2 \ .$$

---

[5] *R. Gray and R. McCue, Shielding Effectiveness Tests on Typical Access Facility Telephone Cables, Harry Diamond Laboratories TM-73-3 (July 1973).*



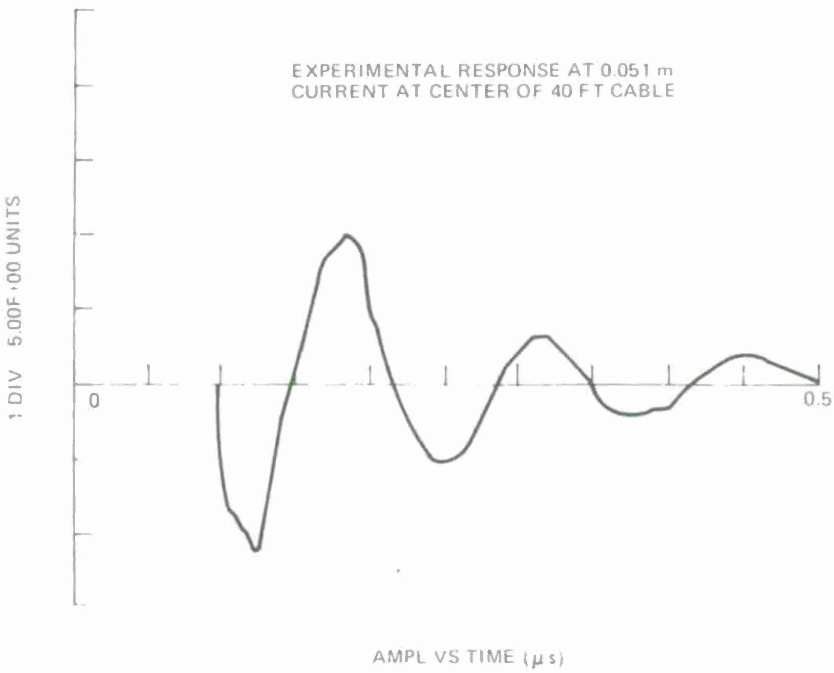


Figure 14. Experimental responses of cable at different heights aboveground.

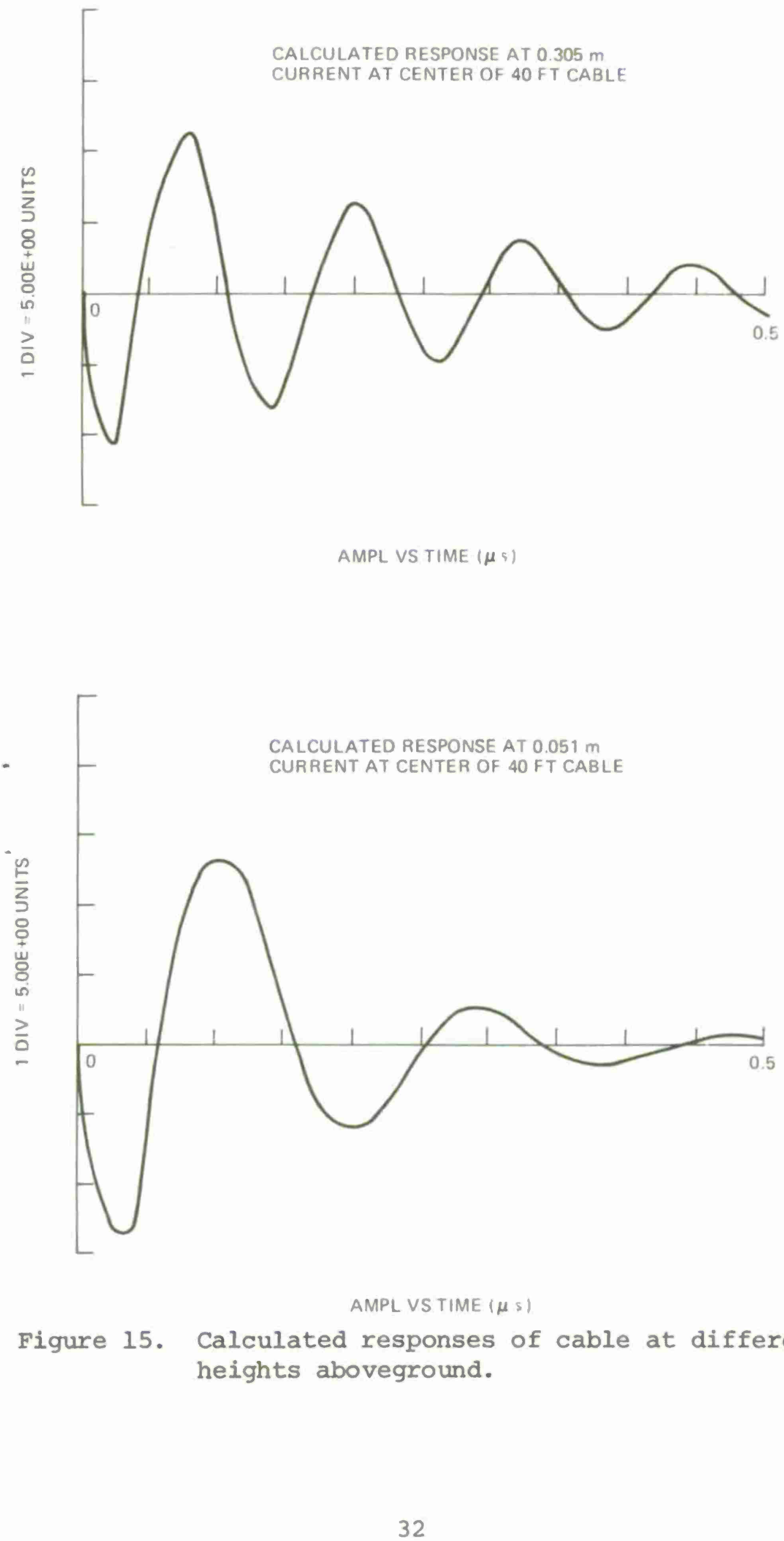


Figure 15. Calculated responses of cable at different heights aboveground.

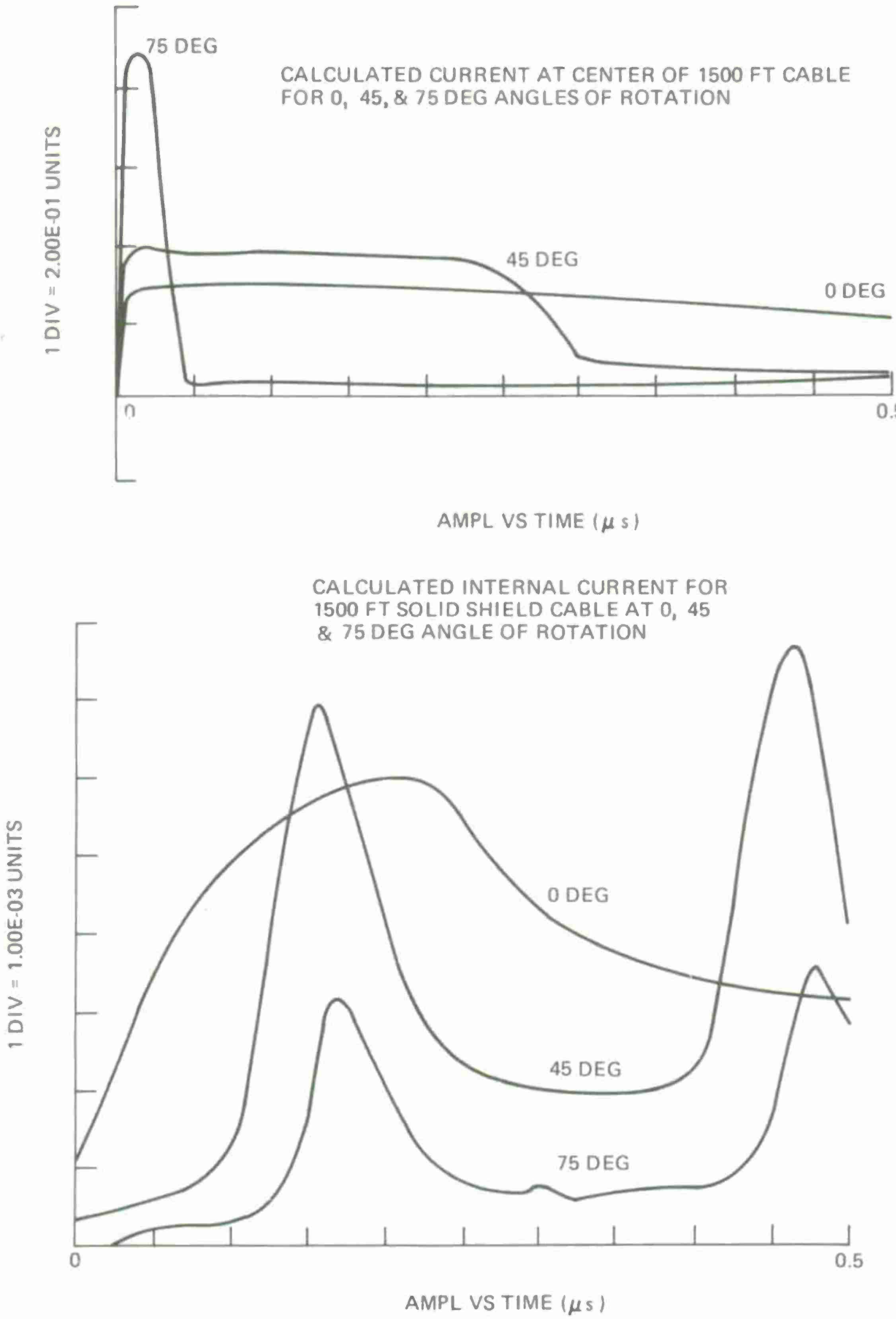


Figure 16. Calculated currents for different angles of rotation.

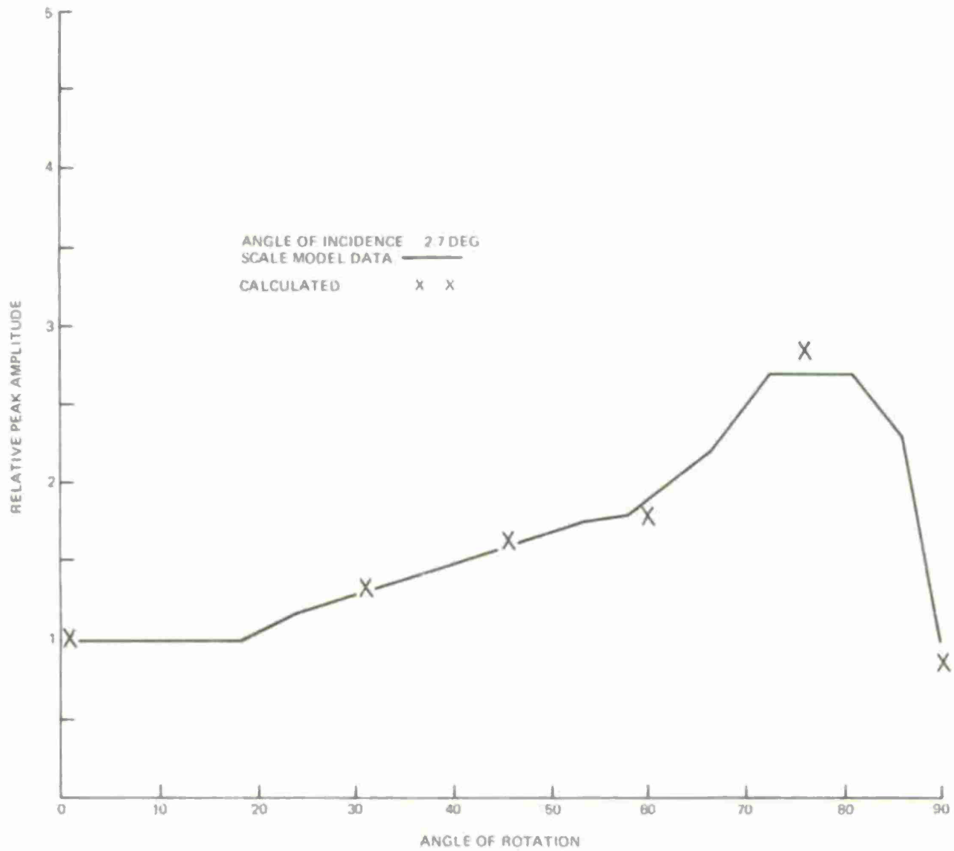
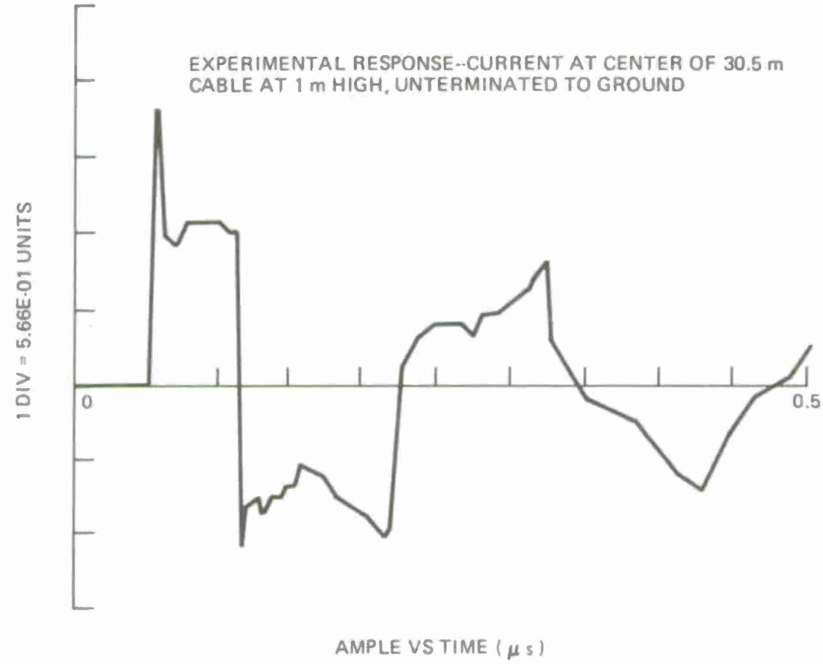


Figure 17. Relative peak amplitude as a function of angle of rotation.

These measured responses and the corresponding calculated results are presented in figures 18 to 21. The two results do not correlate exactly, but the calculations represent the experimental responses enough to allow use of the code to determine where cable-driver and free-field responses diverge. They do so especially since most of the differences are probably due to error in representing the external shield terminating impedances Z_1 and Z_2. The internal responses erred the most at or after a reflection was seen in the shield current (time shift about 50 ns between the two response points, i_s at $\ell/2$ and i_i at ℓ). With the short-circuit termination, the problem lies in defining the inductance of the ground straps used and the impedance of the grounding stakes. For the open-circuit termination, there is a capacitance to ground from the 1-m^3 aluminum box used on the measurement end to house the instrumentation. This box was removed when the external current was measured.



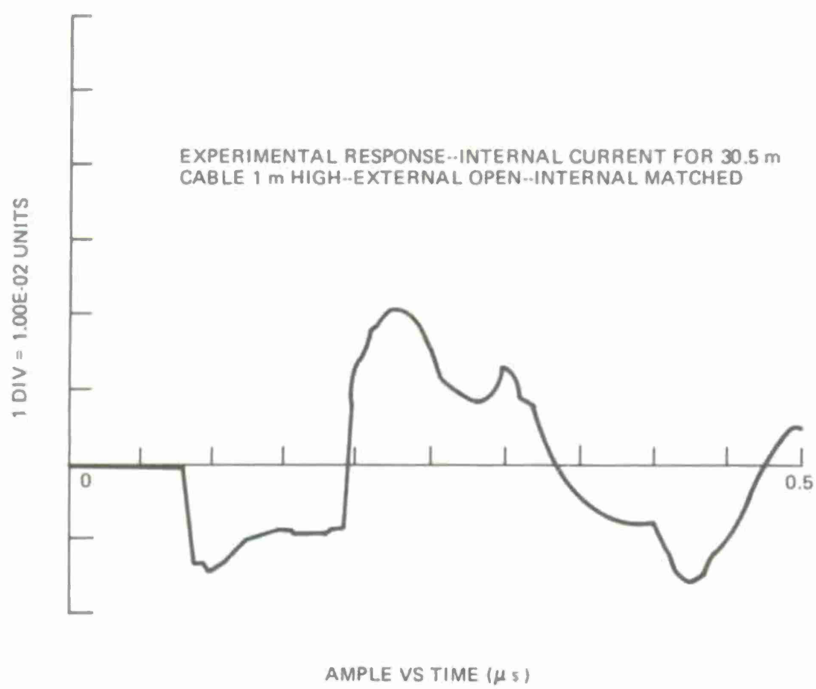
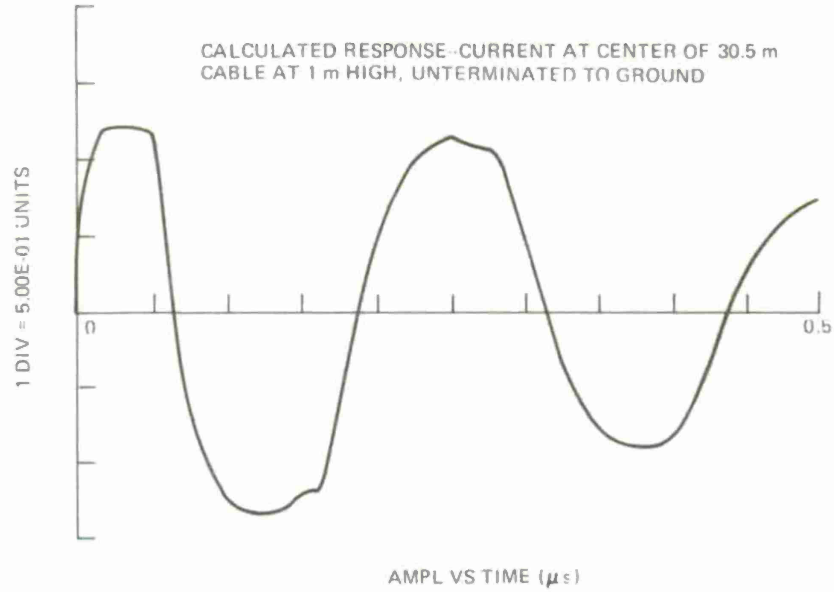


Figure 18. Experimental responses with cable shield unterminated.



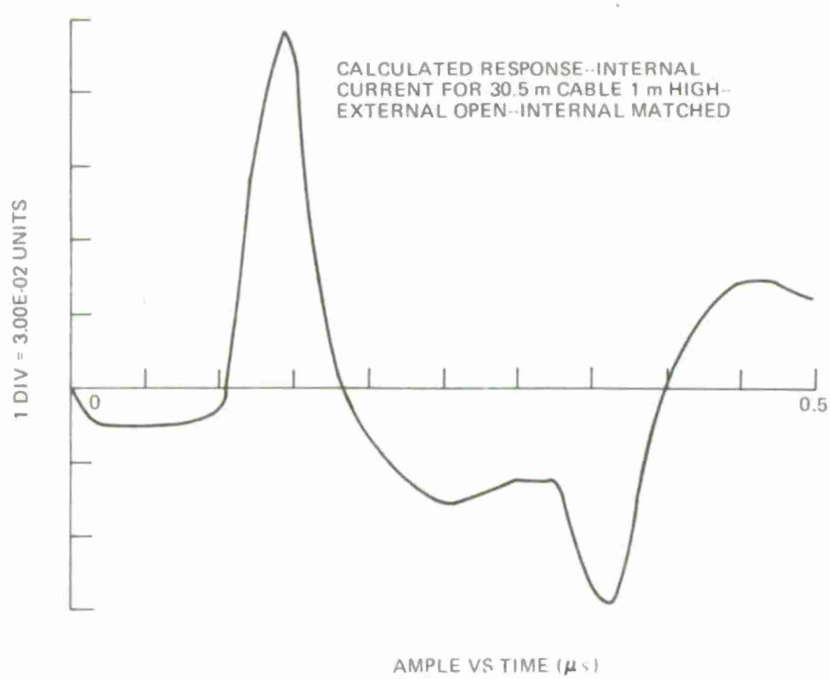
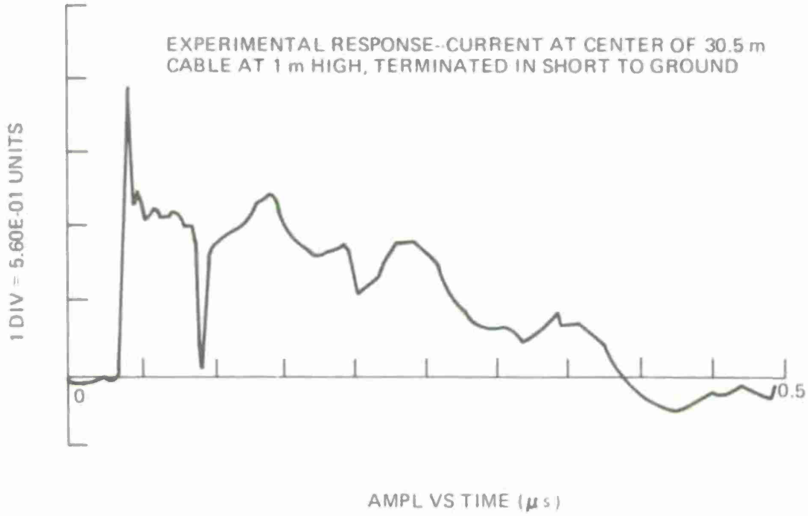


Figure 19. Calculated responses with external shield unterminated.



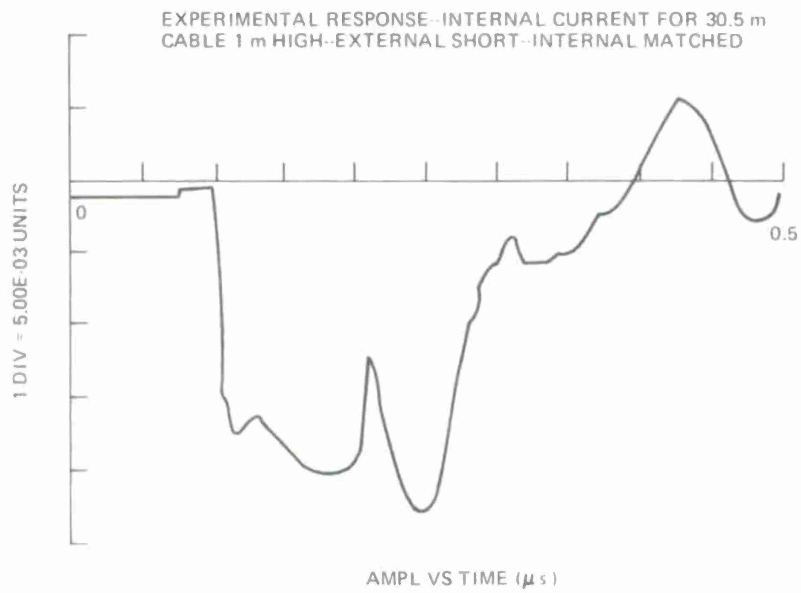
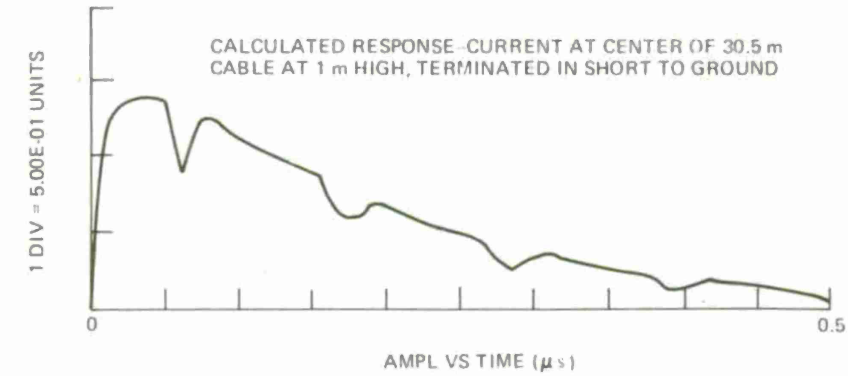


Figure 20. Experimental responses with cable shield terminated to the earth.



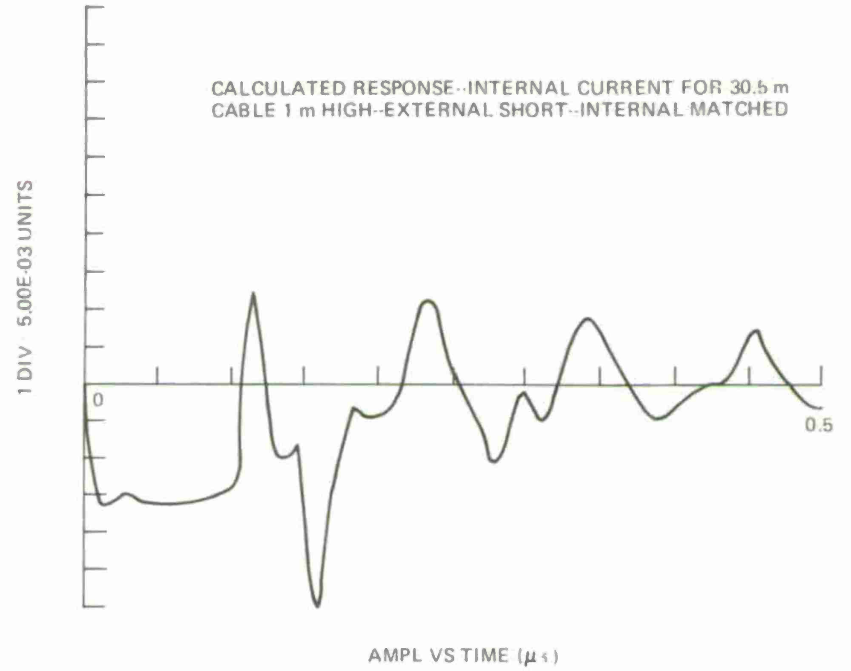


Figure 21. Calculated responses with cable shield terminated to the earth.

Therefore, considering these uncertainties in external terminating impedances and the error due to the field representation used, the correlation between the experimental and calculated responses is sufficient to validate the code for its use here.

5. CABLE DRIVER VERSUS FREE FIELD

5.1 Calculated Comparison

In the previous sections, a general cable shield model was presented, and transmission line solutions for both types of excitation were developed and validated. These solutions are now used to obtain at least an initial idea of how well, if at all, a point source injection system simulates the response of a shielded cable illuminated by an EMP.

Internal current must be calculated for both excitations, with the same internal terminations and the external current waveforms as similar as possible. Since the coaxial-driver solution treats only an overdamped, capacitive-discharge driving source, the free-field calculations have to be limited to conditions that produce a double exponential, external-current waveform. The condition necessary to produce this response is broadside incidence with both ends of the cable terminated in idealized short circuits to the earth.

Calculations were made for three different lengths, 2, 5, and 8 m, of the braided-shield cable. The external current for the coaxial driver was adjusted to match the external current of the free-field calculation. The internal current responses with both ends match-terminated are given in figures 22 and 23. The peak amplitudes for each excitation are about the same, but the durations are consistently longer for the cable-driver calculation. This difference is caused by the fact that the current due to the driver is propagated from one end of the cable to the other, and the current due to the free field occurs simultaneously along the line. The pulse duration, T_f, for the free-field calculation varies proportionately to the one-way propagation time of the internal line, $T_f \sim \ell/v_2$. The driver pulse duration, T_c, is proportional to the sum of the internal and external transit times, $T_c \quad (1/v_1 + 1/v_2)\ell$. The internal current response at each end of the cable is identical for the free-field calculation, but quite different for the coaxial driver, as shown in figure 24. This difference is caused by the difference in phasing for the two excitations. Similar calculations were made for an 8-m solid-shield

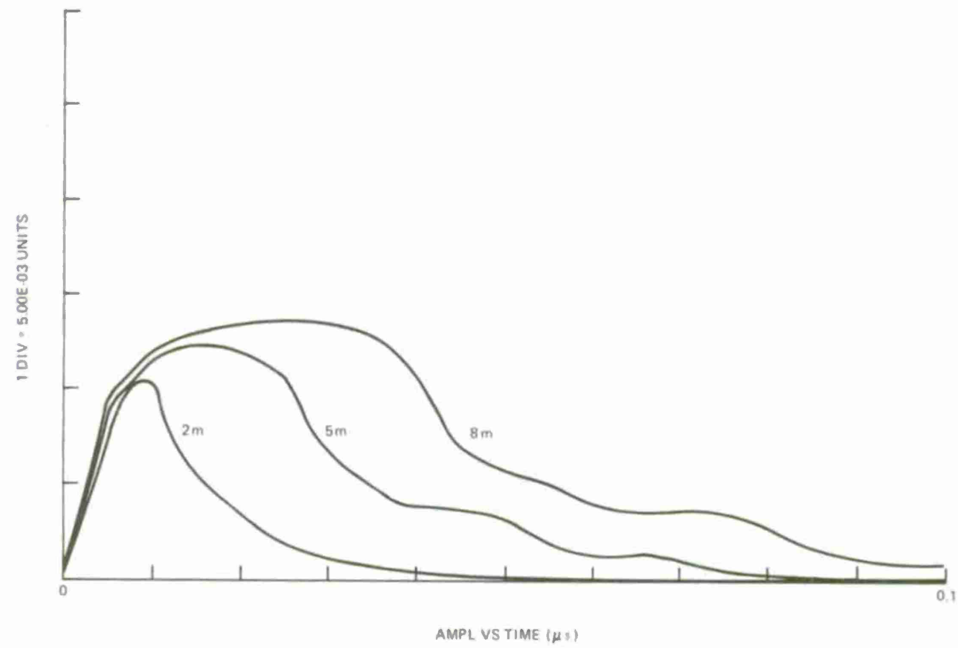


Figure 22. Calculated internal current responses of braided-shield cable for free-field excitation.

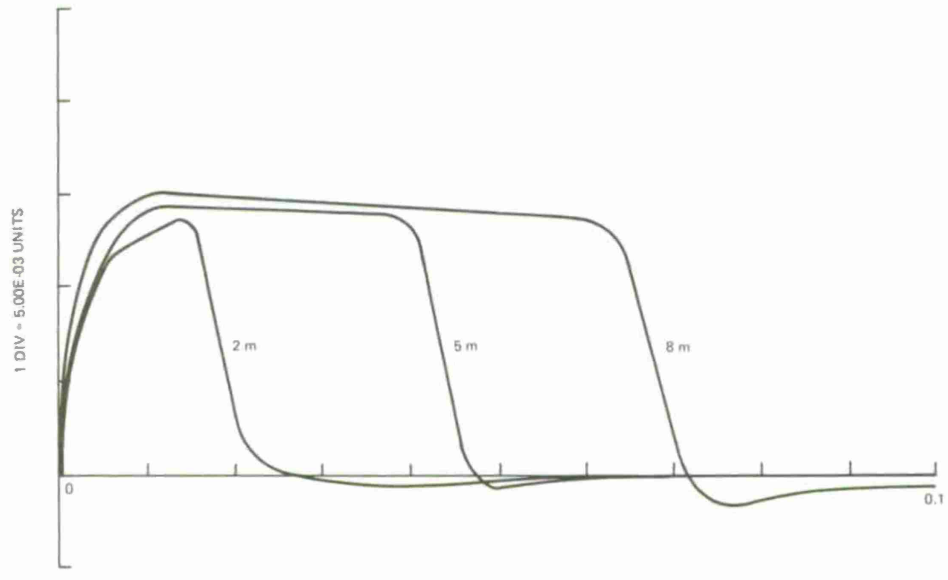


Figure 23. Calculated internal current responses of braided-shield cable for coaxial driver excitation.

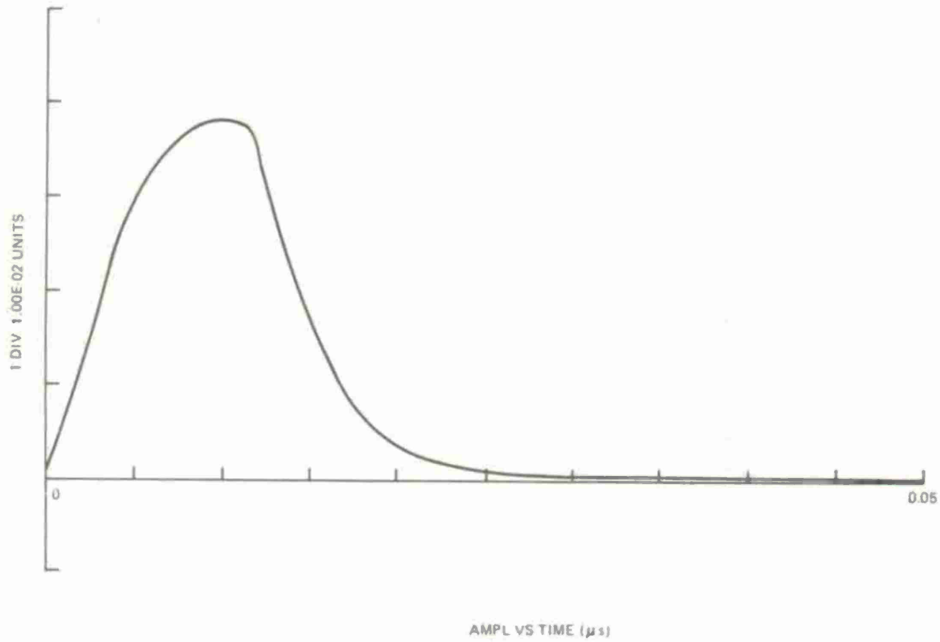


Figure 24. Calculated internal current response at other end of 8-m braided-shield cable for coaxial driver excitation.

cable, and the responses are given in figures 25 and 26. Here, the much greater high-frequency attenuation of the solid shield caused the internal responses to be far less sensitive to the phase differences of the external current.

The differences observed in the calculations indicate that the adequacy of any point source injection system depends on the type of cable shield being driven. It also suggests that the performance of an injection system could be improved by making the phasing of the external current closer to that caused by free-field illumination. It may be made so by use of several distributed point sources along the line, rather than just one, as considered earlier.

5.2 Multiple Point Source Injection System

The same 100-ft braided-shield cable that was used in the free-field experiments was also driven by an injection system inductively coupled to the shield via multiple outputs. The cable was tested in the field with the same terminations as those in the test with the Biconic Simulator. The inductive coupler is a transformer made up

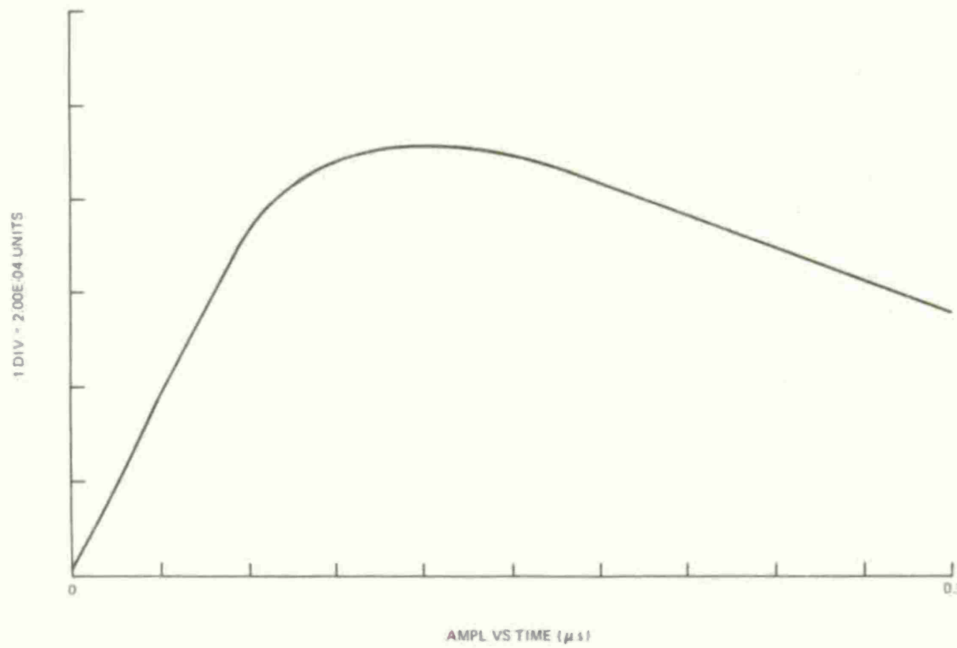


Figure 25. Calculated internal current response of 8-m solid shield cable for free-field excitation.

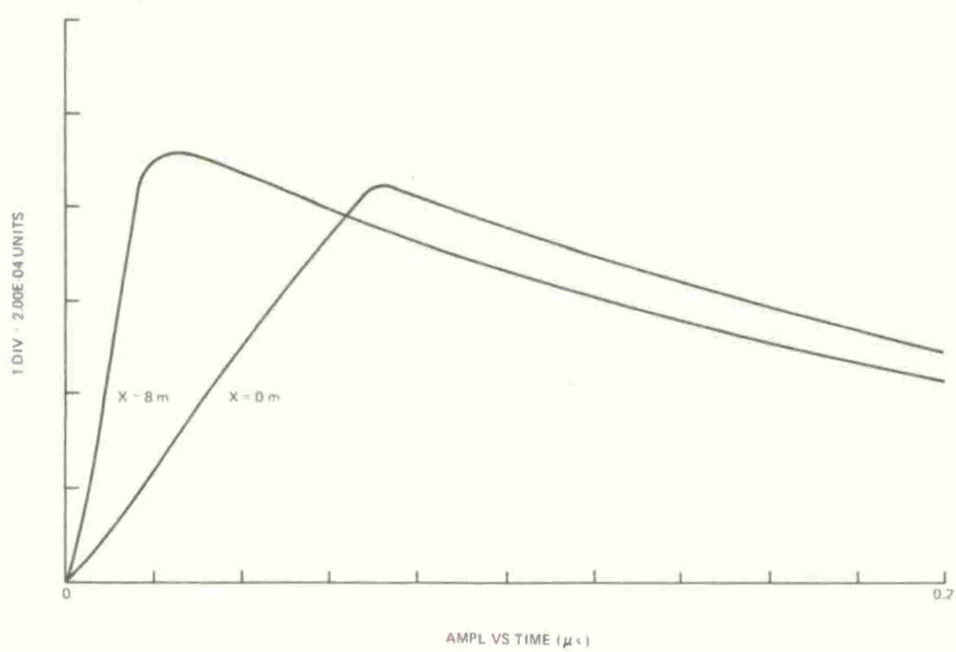


Figure 26. Calculated internal current responses at each end of 8-m solid shield cable for coaxial driver excitation.

of a square ferrite core that is split in the middle, a one-turn primary winding that is driven by a capacitive discharge source, and a one-turn secondary winding that is the cable to be driven. This type of system was used because of the ease in connecting the couplers to the cable. Also, this type of coupler behaves as a series voltage source along the cable, whereas most other types of physically obtainable coupling methods would act like shunt current sources. The major disadvantage of this type of coupling is that both efficiency and secondary waveforms depend very much on the secondary impedance. It is possible to control the secondary response somewhat by use of different types of core material. The type of core material available for this test would only couple a narrow (~30 ns) pulse onto the cable shield due to its high impedance (>300 ohms). This narrow pulse width affected the test results, since it was not possible to couple the desired waveform, but with this problem uncovered, it is possible to factor it out of the results.

Five separate coupling units were used with a spacing of 25 ft along the cable. These units were driven by one source through 50 ft of 50-ohm coaxial line each. The external and internal responses for both external termination conditions are given in figures 27 and 28. Unlike the single source driver, the internal current response was the same at each end of the cable. The narrow current pulse induced by each coupler was the reason for the jagged response. The overall envelopes for the open-circuit termination, though, are very close to those seen for free-field illumination (fig. 18). However, the waveforms for the short-circuit termination do not agree as well with the free-field data (fig. 20). The short-circuit condition has a greater dependence on the late-time characteristic of the driving field. Therefore, the comparisons would probably be improved if a better core material were used. If some imagination is used to smooth out the first half of the internal waveform, some similarity with the free-field response may be seen. The free-field response is basically a rectangular pulse followed by a narrower pulse due to the sheath current reflection from the inductive ground straps. This response also occurs in the cable-driver experiment, but after the smaller pulse, the external current pulse is very different from the free-field case.

In comparing the relative amplitudes of the free-field and multiple driver responses, it is difficult to obtain an exact ratio of the internal current to the external current for the cable-driver experiment because of its jagged waveform. However, using average values for the driver-excited currents indicates that the driver responses are about 30 percent lower than the free-field currents. Better inductive couplers may improve this situation, since the calculated comparisons with near-identical external waveforms were very close.

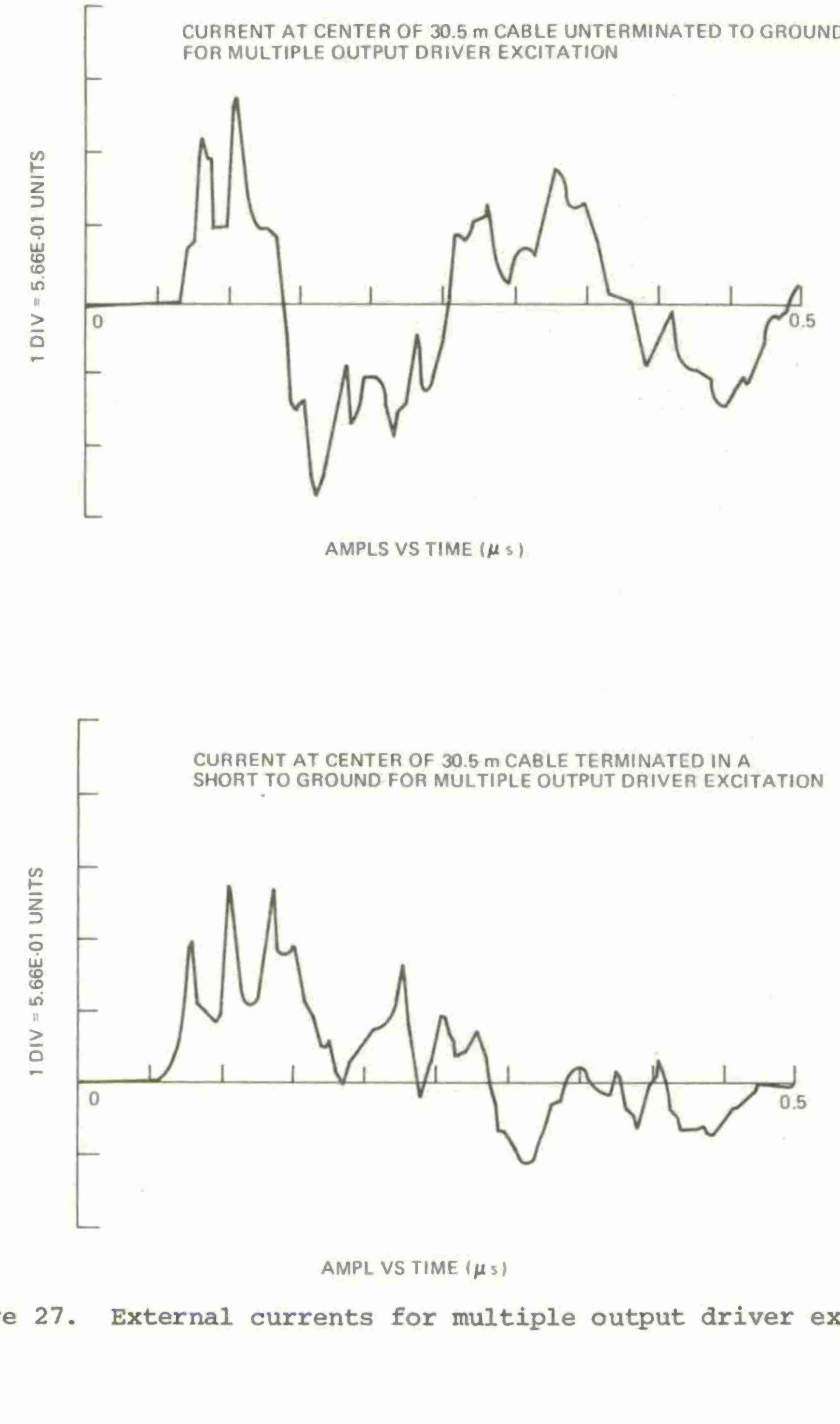
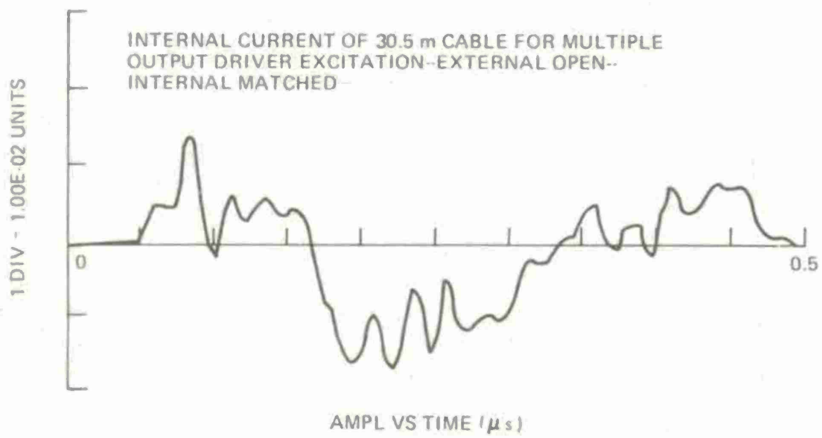


Figure 27. External currents for multiple output driver excitation.



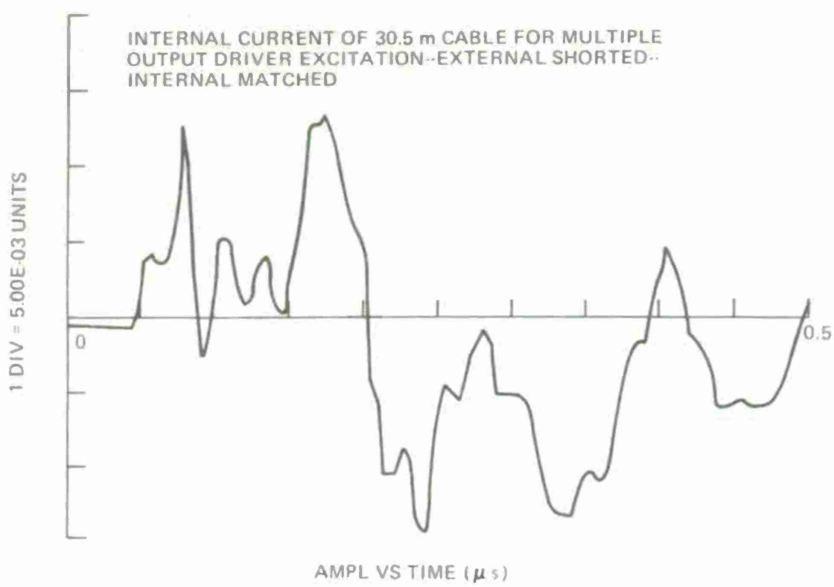


Figure 28. Internal currents for multiple output driver excitation.

6. CONCLUSIONS AND RECOMMENDATIONS

Some basic design techniques have been explored for point source simulation of EMP-produced currents on both shielded and unshielded system penetrations. A high-impedance, shunt-current generator was found to be the most advantageous method of point-source exciting simple unshielded penetrations. A more extensive study of shielded cable excitations was found to be necessary. A general shield coupling model was presented and used in obtaining transmission line solutions for cable responses due to point-source and distributed-source (free-field) excitation of the external current. These solutions were verified with various experimental data and then used to determine some basic areas of applicability of point-source injection simulation.

The validity of this type of simulation was found to be very dependent on the type of shield involved (solid or braided), but not sensitive to the length of the penetration. A multiple-output, inductively coupled injection system was postulated to increase the viability of point-source simulation for braided-shield cables. Experimental results showed that this technique improved the distribution of the external current along the cable shield, thereby better simulating an actual EMP. Some basic problems need to be examined to determine the most efficient type. Also, the transmission of energy to the couplers from the source would need to be improved, since the coaxial lines used in these experiments leaked enough energy to cause unwanted excitation of the test cable. Once these problems were resolved, then a system level validation of the technique would be required before it could be generally applied.

LITERATURE CITED

(1) S. A. Schelkunoff, Electromagnetic Waves, D. Van Nostrand Co., New York (1943).

(2) S. A. Schelkunoff, The Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields, Bell System Technical J. 13 (October 1934).

(3) S. Frankel, Terminal Response of Braided-Shield Cables to External Monochromatic Electromagnetic Fields, Harry Diamond Laboratories TR-1602 (August 1972).

(4) E. F. Vance, Comparison of Electric and Magnetic Coupling through Braided-Wire Shields, TM 18, Air Force Weapons Laboratory, Kirtland Air Force Base, Albuquerque, NM (February 1972).

(5) R. Gray and R. McCue, Shielding Effectiveness Tests on Typical Access Facility Telephone Cables, Harry Diamond Laboratories TM-73-3 (July 1973).

(6) J. Klebers, Time Domain Analysis of the Electromagnetic Field in the Presence of a Finitely Conducting Surface, MERDC (29 January 1969).

DISTRIBUTION

COMMANDER
US ARMY MATERIEL COMMAND
5001 EISENHOWER AVENUE
ALEXANDRIA, VA 22333
ATTN AMCRD, RES, DEV, & ENGR
DIRECTORATE
ATTN AMCRD-WN-RE, JOHN F. CORRIGAN
ATTN TECHNICAL LIBRARY

OFC, CHIEF OF RESEARCH & DEVELOPMENT
USA RSCH & DEV GROUP (EUROPE)
BOX 15
FPR NEW YORK 09510
ATTN LTC EDWARD E. CHICK
CHIEF, MATERIALS BRANCH

COMMANDER
USA ARMAMENTS COMMAND
ROCK ISLAND, IL 61201
ATTN AMSAR-ASF, FUZE DIV
ATTN AMSAR-RDF, SYS DEV DIV - FUZES

COMMANDER
USA MISSILE & MUNITIONS CENTER &
SCHOOL
REDSTONE ARSENAL, AL 35809
ATTN ATSK-CTD-F

DIRECTOR
ARMED FORCES RADIOBIOLOGY RESEARCH
INSTITUTE
DEFENSE NUCLEAR AGENCY
NATIONAL NAVAL MEDICAL CENTER
BETHESDA, MD 20014
ATTN MR. R. CARTER
ATTN TECHNICAL LIBRARY

ASSISTANT TO THE SECRETARY OF DEFENSE
ATOMIC ENERGY
DEPARTMENT OF DEFENSE
WASHINGTON, DC 20301
ATTN DOCUMENT CONTROL

DIRECTOR
DEFENSE ADVANCED RSCH PROJ AGENCY
ARCHITECT BUILDING
1400 WILSON BLVD.
ARLINGTON, VA 22209
ATTN TECHNICAL LIBRARY
ATTN AD/E&PS GEORGE H. HALMEIER

DIRECTOR
DEFENSE CIVIL PREPAREDNESS AGENCY
WASHINGTON, DC 20301
ATTN TS(AED), ROOM 1C 535
ATTN TECHNICAL LIBRARY
ATTN RE(EO)

DEFENSE COMMUNICATION ENGINEER CENTER
1860 WIEHLE AVENUE
RESTON, VA 22090
ATTN CODE R720, C. STANSBERRY
ATTN CODE R410, JAMES W. MCLEAN
ATTN CODE R400
ATTN CODE R124C, TECH LIB

DIRECTOR
DEFENSE COMMUNICATIONS AGENCY
WASHINGTON, DC 20305
ATTN CODE 540.5
ATTN CODE 430
ATTN CODE 930, FRANKLIN D. MOORE
ATTN CODE 930, MONTE I. BURGETT, FR
ATTN TECHNICAL LIBRARY

DEFENSE DOCUMENTATION CENTER
CAMERON STATION
ALEXANDRIA, VA 22314
ATTN TC-TCA, (12 COPIES)

COMMANDER
DEFENSE ELECTRONIC SUPPLY CENTER
1507 WILMINGTON PIKE
DAYTON, OH 45401
ATTN TECH LIB

DIRECTOR
DEFENSE INTELLIGENCE AGENCY
WASHINGTON, DC 20301
ATTN DI-7D, MR. EDWARD OFARRELL
ATTN TECHNICAL LIBRARY

DIRECTOR
DEFENSE NUCLEAR AGENCY
WASHINGTON, DC 20305
ATTN RATN
ATTN DDST
ATTN RAEV
ATTN STTL TECH LIBRARY
ATTN STSI ARCHIVES
ATTN STVL

DIR OF DEFENSE RSCH & ENGINEERING
DEPARTMENT OF DEFENSE
WASHINGTON, DC 20301
ATTN DD/S&SS

HEADQUARTERS
EUROPEAN COMMAND
J-5
APO NEW YORK 09128
ATTN TECHNICAL LIBRARY

COMMANDER
FIELD COMMAND
DEFENSE NUCLEAR AGENCY
KIRTLAND AFB, NM 87115
ATTN FCPR

DIRECTOR
INTERSERVICE NUCLEAR WEAPONS SCHOOL
KIRTLAND AFB, NM 87115
ATTN TECH LIB
ATTN DOCUMENT CONTROL

DIRECTOR
JOINT STRATEGIC TARGET PLANNING
STAFF, JCS
OFFUTT AFB
OMAHA, NB 68113
ATTN STINFO LIBRARY
ATTN JPST
ATTN JSAS

CHIEF
LIVERMORE DIVISION, FIELD COMMAND DNA
LAWRENCE LIVERMORE LABORATORY
P.O. BOX 808
LIVERMORE, CA 94550
ATTN FCPRL
ATTN DOCUMENT CONTROL FOR L-395

NATIONAL COMMUNICATIONS SYSTEM
OFFICE OF THE MANAGER
WASHINGTON, DC 20305
ATTN NCS-TS, CHARLES D. BODSON

COMMANDER
NATIONAL MILITARY COMD SYS SUPPORT CTR
PENTAGON
WASHINGTON, DC 20301
ATTN PAUL COLMAN MD718

DIRECTOR
NATIONAL SECURITY AGENCY
FT. GEORGE G. MEADE, MD 20755
ATTN O. O. VAN GUNTEN-R-425
ATTN TECHNICAL LIBRARY

OJCS/J-6
THE PENTAGON
WASHINGTON, DC 20301
ATTN J-6, ESD-2

DIRECTOR
TELECOMMUNICATIONS & COMD & CON SYS
WASHINGTON, DC 20301
ATTN DEP ASST SEC SYS

COMMANDER-IN-CHIEF
US EUROPEAN COMMAND, JCS
APO NEW YORK 09128
ATTN TECHNICAL LIBRARY

WEAPONS SYSTEMS EVALUATION GROUP
400 ARMY NAVY DRIVE
ARLINGTON, VA 22202
ATTN DOCUMENT CONTROL

COMMANDER
BALLISTIC DEFENSE SYSTEM COMMAND
PO BOX 1500
HUNTSVILLE, AL 35807
ATTN BDMSC-TEN, NOAH J. HURST
ATTN TECHNICAL LIBRARY

DIRECTOR
BMD ADVANCED TECH CTR
HUNTSVILLE OFFICE
PO BOX 1500
HUNTSVILLE, AL 35807
ATTN TECH LIB

CHIEF OF RES, DEV & ACQUISITION
DEPARTMENT OF THE ARMY
WASHINGTON, DC 20310
ATTN DAMA-CSM-N,
LTC E. V. DEBOESER, JR.

DEPARTMENT OF THE ARMY
OFFICE CHIEF OF ENGINEERS
PUBLICATIONS DEPARTMENT
890 SOUTH PICKETT ST
ALEXANDRIA, VA 22304
ATTN DAEN-MCE-D, HAROLD H. MCCAULEY

COMMANDER
PICATINNY ARSENAL
DOVER, NJ 07801
ATTN SARPA-ND-D-B, EDWARD J. ARBER
ATTN PAUL HARRIS
ATTN SARPA-ND-C-E, AMINA NORDIO
ATTN SARPA-ND-D-C-2
ATTN SARPA-ND-W
ATTN HYMAN POSTERNAK
ATTN SARPA-ND-DA-4
ATTN SARPA-TN, BURTON V. FRANKS
ATTN TECHNICAL LIBRARY

COMMANDER
REDSTONE SCIENTIFIC INFORMATION CTR
US ARMY MISSILE COMMAND
REDSTONE ARSENAL, AL 35809
ATTN AMSMI-RBD, CLARA T. ROGERS

COMMANDER
TRASANA
WHITE SANDS MISSILE RANGE, NM 88002
ATTN ATAA-EAC, FRANCIS N. WINANS

COMMANDER
US ARMY ARMOR CENTER
FORT KNOX, KY 40121
ATTN TECHNICAL LIBRARY
ATTN ATSAR-CD-MS

DIRECTOR
US ARMY BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MD 21005
ATTN TECH LIB, EDWARD BAICY
ATTN AMXBR-AM, W. R. VANANTWERP
ATTN AMXBR-VL, JOHN W. KINCH

COMMANDER
US ARMY COMMUNICATIONS COMMAND
FT. HAUCHUCA, AZ 85613
ATTN TECHNICAL LIBRARY

US ARMY COMMUNICATIONS CMD
C-E SERVICES DIVISION
PENTAGON, RM 2D513
WASHINGTON, DC 20310
ATNT CEED-7, WESLEY T. HEATH, JR.

COMMANDER
US ARMY COMMUNICATIONS COMMAND
COMBAT DEVELOPMENT DIVISION
FT. HAUCHUCA, AZ 85613
ATTN ACCM-TD-A, LIBRARY

CHIEF
US ARMY COMMUNICATIONS SYSTEMS AGENCY
FORT MONMOUTH, NJ 07703
ATTN SCCM-AD-SV (LIBRARY)

COMMANDER
US ARMY COMPUTER SYSTEMS COMMAND
FORT BELVOIR, VA 22060
ATTN TECHNICAL LIBRARY

COMMANDER
US ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NJ 07703
ATTN AMSEL-CT-HDK, ABRAHAM E. COHEN
ATTN AMSEL-CE, T. PREIFFER
ATTN AMSEL-TL-MD, GERHART K. GAULE
ATTN AMSEL-GG-TD, W. R. WERK
ATTN AMSEL-PL-ENV, HANS A. BOMKE
ATTN AMSEL-TL-ME, M. W. POMERANTZ
ATTN AMSEL-TL-IR, ROBERT A. FREIBERG
ATTN AMSEL-WL-D
ATTN AMSEL-NL-D

COMMANDING OFFICER
US ARMY ELECTRONICS COMMAND
NIGHT VISION LABORATORY
FORT BELVOIR, VA 22060
ATTN TECHNICAL LIBRARY

COMMANDER
US ARMY ELECTRONICS PROVING GROUND
FORT HUACHUCA, AZ 85613
ATTN STEEP-MT-M, GERALD W. DURBIN

PROJECT ENGINEER
US ARMY ENGINEER DIST HUNTSVILLE
PO BOX 1600, WEST STATION
HUNTSVILLE, AL 35807
ATTN F. SMITH

DIVISION ENGINEER
US ARMY ENGINEER DISTRICT, MISSOURI RIVER
P.O. BOX 103 DOWNTOWN STATION
OMAHA, NB 68101
ATTN MRDED-MC, MR. FLOYD L. HAZLETT

COMMANDER-IN-CHIEF
US ARMY EUROPE AND SEVENTH ARMY
APO NEW YORK 09403
ATTN TECHNICAL LIBRARY

COMMANDANT
US ARMY FIELD ARTILLERY SCHOOL
FORT SILL, OK 73503
ATTN ATSFA-CTD-ME, HARLEY MOBERG
ATTN TECH LIBRARY

COMMANDER
US ARMY MATERIALS & MECHANICS RESEARCH CENTER
WATERTOWN, MA 02172
ATTN TECHNICAL LIBRARY
ATTN AMXMR-HH, JOHN F. DIGNAM

DIRECTOR
US ARMY MATERIAL SYS ANALYSIS AGCY
US ARMY ABERDEEN R&D CENTER
ABERDEEN PROVING GROUDN, MD 21005
ATTN AMXSY-CC, D. R. BARTHEL
ATTN TECHNICAL LIBRARY

COMMANDER
US ARMY MISSILE COMMAND
REDSTONE ARSENAL
HUNTSVILLE, AL 35809
ATTN AMSMI-RGP, HUGH GREEN
ATTN AMCPM-LCEX, HOWARD H. HENRIKSEN
ATTN AMCPM-PE-EA, WALLACE O. WAGNER
ATTN TECHNICAL LIBRARY
ATTN AMSI-RGP, VICTOR W. RUWE

COMMANDER
US ARMY MOBILITY EQUIPMENT R & D CENTER
FORT BELVOIR, VA 22060
ATTN STSFB-MW, JOHN W. BOND, JR.
ATTN TECHNICAL LIBRARY

COMMANDER
US ARMY NUCLEAR AGENCY
FORT BLISS, TX 79916
ATTN ATCN-W, LTC LEONARD A. SLUGA
ATTN TECH LIB

COMMANDER
US ARMY SECURITY AGENCY
ARLINGTON HALL STATION
4000 ARLINGTON BLVD
ARLINGTON, VA 22212
ATTN IARD-T, DR. R. H. BURKHARDT
ATTN TECHNICAL LIBRARY

COMMANDANT
US ARMY SOUTHEASTERN SIGNAL SCHOOL
FORT GORDON, VA 30905
ATTN ATSO-CTD-CS, CPT G. M. ALEXANDER
ATTN TECH LIBRARY

PROJECT MANAGER
US ARMY TACTICAL DATA SYSTEMS, AMC
FORT MONMOUTH, NJ 07703
ATTN TECH LIBRARY
ATTN DWAINE B. HUEWE

COMMANDER
US ARMY TANK AUTOMOTIVE COMMAND
WARREN, MI 48089
ATTN AMCPM-GCM-SW, L. A. WOLCOTT
ATTN AMSTA-RHM, ILT PETER A. HASEK
ATTN TECH LIBRARY

COMMANDER
US ARMY TEST AND EVALUATION COMMAND
ABERDEEN PROVING GROUND, MD 21005
ATTN AMSTE-EL, R. I. KOLCHIN
ATTN AMSTE-NB, R. R. GALASSO
ATTN TECHNICAL LIBRARY

COMMANDER
US ARMY TRAINING AND DOCTRINE COMMAND
FORT MONROE, VA 23651
ATTN TECH LIBRARY

COMMANDER
WHITE SANDS MISSILE RANGE
WHITE SANDS MISSILE RANGE, NM 88002
ATTN TECHNICAL LIBRARY
ATTN STEWS-TE-NT, MR. MARVIN P. SQUIRES

CHIEF OF NAVAL OPERATIONS
NAVY DEPARTMENT
WASHINGTON, DC 20350
ATTN CODE 604C3, ROBERT PIACESI

CHIEF OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
ARLINGTON, VA 22217
ATTN TECHNICAL LIBRARY
ATTN CODE 427
ATTN CODE 464, THOMAS P. QUINN

OFFICER-IN-CHARGE
CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
FORT HUENEME, CA 93041
ATTN TECHNICAL LIBRARY
ATTN CODE L31

COMMANDER
NAVAL AIR SYSTEMS COMMAND
HEADQUARTERS
WASHINGTON, DC 21360
ATTN TECH LIB
ATTN LCDR HUGO HART (AIR-350-F)

COMMANDING OFFICER
NAVAL AMMUNITION DEPOT
CRANE, IN 47522
ATTN TECHNICAL LIBRARY
ATTN CODE 7024, JAMES L. RAMSEY

COMMANDER
NAVAL ELECTRONIC SYSTEMS COMMAND
HEADQUARTERS
WASHINGTON, DC 20360
ATTN TECH LIB
ATTN PME117-215A, GUNTER BRUNHART
ATTN PME 117-21
ATTN PME 117-T

COMMANDER
NAVAL ELECTRONICS LABORATORY CENTER
SAN DIEGO, CA 92152
ATTN CODE 2400, S. W. LICHTMAN
ATTN CODE 2200 1,
VERNE E. HILDEBRAND
ATTN CODE 3100, E. E. MCCOWN
ATTN TECHNICAL LIBRARY

COMMANDING OFFICER
NAVAL INTELLIGENCE SUPPORT CENTER
4301 SUITLAND ROAD, BLDG 5
WASHINGTON, DC 20390
ATTN TECHNICAL LIBRARY

SUPERINTENDENT
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93940
ATTN CODE 2124, TECH RPTS LIBRARIAN

DIRECTOR
NAVAL RESEARCH LABORATORY
WASHINGTON, DC 20375
ATTN CODE 6631, JAMES C. RITTER
ATTN CODE 4004, EMANUAL L. BRANCATO
ATTN CODE 2027, TECH LIB
ATTN CODE 2627, DORIS R. FOLEN
ATTN CODE 7701, JACK D. BROWN
ATTN CODE 464, R. GRAGEN JOINER
ATTN CODE 7706, JAY P. BORIS

COMMANDER
NAVAL SEA SYSTEMS COMMAND
NAVY DEPARTMENT
WASHINGTON, DC 20362
ATTN SEA-9931, RILEY B. LANE

COMMANDER
NAVAL SHIP ENGINEERING CENTER
CENTER BUILDING
HYATTSVILLE, MD 20782
ATTN TECHNICAL LIBRARY
ATTN CODE 6174D2, EDWARD F. DUFFY

COMMANDER
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MD 20910
ATTN CODE 730, TECH LIB
ATTN CODE 431, EDWIN B. DEAN
ATTN CODE 1224, NAVY NUC PRGMS OFF
ATTN CODE 431, EDWIN R. RATHBURN
ATTN CODE 431, JOHN H. MALLOY
ATTN CODE WR43

COMMANDER
NAVAL SURFACE WEAPONS CENTER
DAHLGREN LABORATORY
DAHLGREN, VA 22448
ATTN CODE FUR, ROBERT A. AMADORI
ATTN TECHNICAL LIBRARY

COM HEADQUARTERS
NAVAL TELECOMMUNICATIONS COMMAND
NAV TEL COM HEADQUARTERS
4401 MASSACHUSETTS AVE, NW
WASHINGTON, DC 20390
ATTN TECH LIB

COMMANDER
NAVAL UNDERSEA CENTER
SAN DIEGO, CA 92152
ATTN CODE 608, CLARENCE F. RANSTEDT

COMMANDER
NAVAL WEAPONS CENTER
CHINA LAKE, CA 93555
ATTN CODE 533, TECHNICAL LIBRARY

COMMANDING OFFICER
NAVAL WEAPONS EVALUATION FACILITY
KIRTLAND AIR FORCE BASE
ALBUQUERQUE, NM 87117
ATTN LAWRENCE R. OLIVER
ATTN CODE ATG, MR. STANLEY

COMMANDING OFFICER
NAVY ASTRONAUTICS GROUP
POINT MUGU, CA 93042
ATTN TECH LIB

COMMANDING OFFICER
NUCLEAR WEAPONS TRAINING CENTER
PACIFIC
NAVAL AIR STATION, NORTH ISLAND
SAN DIEGO, CA 92135
ATTN CODE 50

DIRECTOR
STRATEGIC SYSTEMS PROJECT OFFICE
NAVY DEPARTMENT
WASHINGTON, DC 20376
ATTN SP2701, JOHN W. PITSENBERGER
ATTN NSP-43, TECH LIB
ATTN NSP-230, DAVID GOLD
ATTN NSP-2342, RICHARD L. COLEMAN

COMMANDER
US NAVAL COASTAL SYSTEMS LABORATORY
PANAMA CITY, FL 32401
ATTN TECH LIB

COMMANDER-IN-CHIEF
US PACIFIC FLEET
FPO SAN FRANCISCO 96610
ATTN DOCUMENT CONTROL

COMMANDER
ADC/DF
ENT AFB, CO 80912
ATTN DEEDS, JOSEPH C. BRANNAN
ATTN DDEEN

COMMANDER
ADC/XP
ENT AFB, CO 80912
ATTN XPQD, MAJ G. KUCH
ATTN XPDQ

COMMANDER
AERONAUTICAL SYSTEMS DIVISION, AFSC
WRIGHT-PATTERSON AFB, OH 45433
ATTN TECHNICAL LIBRARY
ATTN ASD-YH-EX

AF ARMAMENT LABORATORY, AFSC
EGLIN AFB, FL 32542
ATTN DLOSL-LIB

AF CAMBRIDGE RSCH LABS, AFSC
L. G. HANSCOM FIELD
BEDFORD, MA 01730
ATTN EMERY CORMIER

AF WEAPONS LABORATORY, AFSC
KIRTLAND AFB, NM 87117
ATTN EL, MR. JOHN DARRAH
ATTN DYX, DONALD C. WUNSCH
ATTN SAT
ATTN ELA
ATTN ELC
ATTN ELP, CHARLES E. BAUM
ATTN EL
ATTN SAS
ATTN SUL
ATTN ELA, J. P. CASTILO
ATTN EL (LIBRARY)

AFTAC
PATRICK AFB, FL 32925
ATTN TECH LIB

AIR FORCE AVIONICS LABORATORY, AFSC
WRIGHT-PATTERSON AFB, OH 45433
ATTN TECH LIB

HEADQUARTERS
AIR FORCE SYSTEMS COMMAND
ANDREWS AFB
WASHINGTON, DC 20331
ATTN TECHNICAL LIBRARY

COMMANDER
AIR UNIVERSITY
MAXWELL AFB, AL 36112
ATTN AUL/LSE-70-250

HEADQUARTERS
ELECTRONIC SYSTEMS DIVISION, (AFSC)
L. G. HANSCOM FIELD
BEDFORD, MA 01730
ATTN YWEI
ATTN YSEV, LTC DAVID C. SPARKS
ATTN TECHNICAL LIBRARY
ATTN XRT, LTC JOHN M. JASKINKI

COMMANDER
FOREIGN TECHNOLOGY DIVISION, AFSC
WRIGHT-PATTERSON AFB, OH 45433
ATTN TD-BTA, LIBRARY
ATTN ETET, CAPT RICHARD C. HUSEMANN

HQ USAF/RD
WASHINGTON, DC 20330
ATTN RDQPN

COMMANDER
OGDEN AIR LOGISTICS CENTER
HILL AFB, UT 84401
ATTN TECH LIB
ATTN MMFWM, ROBERT JOFFS

COMMANDER
ROME AIR DEVELOPMENT CENTER, AFSC
GRIFFISS AFB, NY 13440
ATTN EMTLD, DDC LIBRARY

COMMANDER
SACRAMENTO AIR LOGISTICS CENTER
MCCLELLAN AFB, CA 95652
ATTN TECHNICAL LIBRARY

SAMSO/DY
POST OFFICE BOX 92960
WORLDWAY POSTAL CENTER
LOS ANGELES, CA 90009
ATTN DYS, MAJ LARRY A, DARDA

DISTRIBUTION (CONT'D)

SAMSO/MN
NORTON AFB, CA 92409
ATTN MNNH, CAPT B. STEWART
ATTN MNNH, CAPT MICHAEL V. BELL

SAMSO/SK
POST OFFICE BOX 92960
WORLDWAY POSTAL CENTER
LOS ANGELES, CA 90009
ATTN SKF, PETER H. STADLER

SAMSO/YD
POST OFFICE BOX 92960
WORLDWAY POSTAL CENTER
LOS ANGELES, CA 90009
ATTN YDD, MAJ M. F. SCHNEIDER

COMMANDER IN CHIEF
STRATEGIC AIR COMMAND
OFFUTT AFB, NB 68113
ATTN NRI-STINFO LIBRARY
ATTN DEF, FRANK N. BOUSHA
ATTN XPFS, MAJ BRIAN STEPHAN

544IES
OFFUTT AFB, NB 68113
ATTN RDPO, LT ALAN B. MERRILL

DIVISION OF MILITARY APPLICATION
US ENERGY RSCH & DEV ADMIN
WASHINGTON, DC 20545
ATTN TECHNICAL LIBRARY

EG&G, INC.
LOS ALAMOS DIVISION
PO BOX 809
LOS ALAMOS, NM 85544
ATTN TECH LIB
ATTN L. DETCH

UNIVERSITY OF CALIFORNIA
LAWRENCE BERKELEY LABORATORY
LIBRARY BLG 50, ROOM 134
BERKELEY, CA 94720
ATTN LIBRARY BLDG 50, RM 134

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE LABORATORY
PO BOX 808
LIVERMORE, CA 94550
ATTN L-156, ROBERT A. ANDERSON
ATTN FREDERICK R. KOVAR, L-94
ATTN LELAND C. LOQUIST
ATTN TECH INFO DEPT, L-3
ATTN TERRY R. DONICH
ATTN WILLIAM J. HOGAN, L-531
ATTN HANS KRUGER, L-96
ATTN E. K. MILLER, 1-156
ATTN DONALD J. MEEKER, L-153
ATTN LOUIS F. WOUTERS, L-24

LOS ALAMOS SCIENTIFIC LABORATORY
P.O. BOX 1663
LOS ALAMOS, NM 87544
ATTN REPORTS LIBRARY
ATTN ARTHUR FREED
ATTN RICHARD L. WAKEFIELD

SANDIA LABORATORIES
LIVERMORE LABORATORY
PO BOX 969
LIVERMORE, CA 94550
ATTN TECHNICAL LIBRARY

SANDIA LABORATORIES
PO BOX 5800
ALBUQUERQUE, NM 87115
ATTN ORD 9353, R. L. PARKER
ATTN GERALD W. BARR, 1114
ATTN 3141 SANDIA RPT COLL
ATTN CHARLES N. VITTITOE
ATTN ELMER F. HARTMAN

US ENERGY RSCH & DEV ADMIN
ALBUQUERQUE OPERATIONS OFFICE
PO BOX 5400
ALBUQUERQUE, NM 87115
ATTN WSSB
ATTN TECH LIBRARY

UNION CARBIDE CORPORATION
HOLIFIELD NATIONAL LABORATORY
P.O. BOX X
OAK RIDGE, TN 37830
ATTN PAUL R. BARNES
ATTN TECH LIBRARY

CENTRAL INTELLIGENCE AGENCY
ATTN: RD/SI RM 5G48, HQ BLDG
WASHINGTON, DC 20505
ATTN WILLIAM A. DECKER
ATTN TECHNICAL LIBRARY

ADMINISTRATOR
DEFENSE ELECTRIC POWER ADMINISTRATION
DEPARTMENT OF THE INTERIOR
INTERIOR SOUTH BLDG. 312
WASHINGTON, DC 20240
ATTN DOCUMENT CONTROL

DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, DC 20234
ATTN TECHNICAL LIBRARY

DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC
ADMINISTRATION
ENVIRONMENTAL RESEARCH LABORATORIES
BOULDER, CO 80302
ATTN DOCUMENT LIBRARY

FEDERAL AVIATION ADMINISTRATION
HEADQUARTERS SECURITY BRANCH, ASE-210
800 INDEPENDENCE AVENUE, S.W.
WASHINGTON, DC 20591
ATTN FREDRICK S. SAKATE, ARD-350
ATTN ARD-350

NASA
600 INDEPENDENCE AVENUE, SW
WASHINGTON, DC 20546
ATTN TECHNICAL LIBRARY
ATTN CODE RFS GUID CEN & INFO SYS

NASA
LEWIS RESEARCH CENTER
21000 BROOKPARK ROAD
CLEVELAND, OH 44135
ATTN LIBRARY

AEROJET ELECTRO-SYSTEMS CO. DIV.
AEROJET-GENERAL CORPORATION
P.O. BOX 296
AZUSA, CA 91702
ATTN TECH LIBRARY
ATTN THOMAS D. HANSCOME, B170/D6711

AERONUTRONIC FORD CORPORATION
AEROSPACE & COMMUNICATIONS OPS
AERONUTRONIC DIVISION
FORD & JAMBOREE ROADS
NEWPORT BEACH, CA 92663
ATTN E. R. PONCELET, JR.
ATTN KEN C. ATTINGER
ATTN TECH INFO SECTION

AERONUTRONIC FORD CORPORATION
WESTERN DEVELOPMENT LABORATORIES DIV
3939 FABIAN WAY
PALO ALTO, CA 94303
ATTN N. T. MATTINGLEY, MS X22
ATTN SAMUEL R. CRAWFORD, MS 531
ATTN LIBRARY

AEROSPACE CORPORATION
PO BOX 92957
LOS ANGELES, CA 90009
ATTN C. B. PEARLSTON
ATTN IRVING M. GARFUNKEL
ATTN JULIAN REINHEIMER
ATTN LIBRARY
ATTN MELVIN J. BERNSTEIN
ATTN NORMAN D. STOCKWELL
ATTN S. P. BOWER
ATTN BAL KRISHAN

AVCO RESEARCH & SYSTEMS GROUP
201 LOWELL STREET
WILMINGTON, MA 01887
ATTN RESEARCH LIBRARY, A830, RM 7201

BATTELLE MEMORIAL INSTITUTE
505 KING AVENUE
COLUMBUS, OH 43201
ATTN TECHNICAL LIBRARY
ATTN DAVID A. DINGEE
ATTN STOIAC

BDM CORPORATION, THE
1920 ALINE AVE
VIENNA, VA 22180
ATTN TECHNICAL LIBRARY

BDM CORPORATION, THE
PO BOX 9274
ALBUQUERQUE INTERNATIONAL
ALBUQUERQUE, NM 87119
ATTN WILLIAM DRUEN
ATTN B. GAGE
ATTN T. H. NEIGHBORS
ATTN TECH LIB
ATTN ROBERT B. BUCHANAN

BELL AEROSPACE COMPANY
DIVISION OF TEXTRON, INC.
P.O. BOX 1
BUFFALO, NY 14240
ATTN TECHNICAL LIBRARY
ATTN CARL B. SCHOCH, WEPS EFFECTS GP
ATTN MARTIN A. HENRY

BENDIX CORPORATION, THE
COMMUNICATION DIVISION
EAST JOPPA ROAD - TOWSON
BALTIMORE, MD 21204
ATTN DOCUMENT CONTROL

BENDIX CORPORATION, THE
RESEARCH LABORATORIES DIV
BENDIX CENTER
SOUTHFIELD, MI 48075
ATTN TECH LIB
ATTN MGR PROGM DEV, DONALD J. NIEHAUS

BENDIX CORPORATION, THE
NAVIGATION AND CONTROL DIVISION
TETERBORO, NJ 07608
ATTN TECH LIB

BOEING COMPANY, THE
PO BOX 3707
SEATTLE, WA 98124
ATTN HOWARD W. WICKLEIN, MS 17-11
ATTN D. E. ISBELL
ATTN DAVID DYE, MS 87-75
ATTN DAVID KEMLE
ATTN AEROSPACE LIBRARY

BOOZ-ALLEN AND HAMILTON, INC.
106 APPLE STREET
NEW SHREWSBURY, NJ 07724
ATTN TECH LIB
ATTN R. J. CHRISNER

BROWN ENGINEERING COMPANY, INC.
CUMMINGS RESEARCH PARK
HUNTSVILLE, AL 35807
ATTN JOHN M, MCSWAIN, MS 18
ATTN TECH LIB, MS12, P. SHELTON

BURROUGHS CORPORATION
FEDERAL AND SPECIAL SYSTEMS GROUP
CENTRAL AVE AND ROUTE 252
PO BOX 517
PAOLI, PA 29301
ATTN ANGELO J. MAURIELLO
ATTN TECH LIB

CALSPAN CORPORATION
PO BOX 235
BUFFALO, NY 14221
ATTN TECH LIBRARY

CHARLES STARK DRAPER LABORATORY INC.
68 ALBANY STREET
CAMBRIDGE, MA 02139
ATTN TECH LIB
ATTN KENNETH FERTIG

CINCINNATI ELECTRONICS CORPORATION
2630 GLENDALE - MILFORD ROAD
CINCINNATI, OH 45241
ATTN TECH LIB
ATTN C. R. STUMP

COMPUTER SCIENCES CORPORATION
P.O. BOX 530
6565 ARLINGTON BLVD
FALLS CHURCH, VA 22046
ATTN TECH LIB

COMPUTER SCIENCES CORPORATION
201 LA VETA DRIVE, NE
ALBUQUERQUE, NM 87108
ATTN RICHARD H. DICKHAUT
ATTN ALVIN SCHIFF

CUTLER-HAMMER, INC.
AIL DIVISION
COMAC ROAD
DEER PARK, NY 11729
ATTN CENTRAL TECH FILES, ANN ANTHONY

DENVER, UNIVERSITY OF
COLORADO SEMINARY
PO BOX 10127
DENVER, CO 80210
ATTN FRED P. VENDITTI
ATTN TECH LIB

DIKEWOOD CORPORATION, THE
1009 BRADBURY DRIVE, SE
UNIVERSITY RESEARCH PARK
ALBUQUERQUE, NM 87106
ATTN TECH LIB
ATTN L. WAYNE DAVIS
ATTN K. LEE

E-SYSTEMS, INC.
GREENVILLE DIVISION
PO BOX 1056
GREENVILLE, TX 75401
ATTN LIBRARY 8-50100

EFFECTS TECHNOLOGY, INC.
5383 HOLISTER AVENUE
SANTA BARBARA, CA 93105
ATTN EDWARD JOHN STEELE
ATTN TECH LIB

EG&G, INC.
ALBUQUERQUE DIVISION
PO BOX 10218
ALBUQUERQUE, NM 87114
ATTN TECHNICAL LIBRARY

ESL, INC.
495 JAVA DRIVE
SUNNYVALE, CA 94086
ATTN TECHNICAL LIBRARY
ATTN WILLIAM METZER

EXPERIMENTAL AND MATHEMATICAL PHYSICS CONSULTANTS
P. O. BOX 66331
LOS ANGELES, CA 90066
ATTN THOMAS M. JORDAN

FAIRCHILD CAMERA AND INSTRUMENT CORPORATION
464 ELLIS STREET
MOUNTAIN VIEW, CA 94040
ATTN 2-233, MR. DAVID K. MYERS
ATTN TECH LIB

FAIRCHILD INDUSTRIES, INC.
SHERMAN FAIRCHILD TECHNOLOGY CENTER
20301 CENTURY BOULEVARD
GERMANTOWN, MD 20767
ATTN LEONARD J. SCHREIBER
ATTN TECH LIB

FRANKLIN INSTITUTE, THE
20TH STREET AND PARKWAY
PHILADELPHIA, PA 19103
ATTN RAMIE H. THOMPSON
ATTN TECH LIB

GARRETT CORPORATION
9851 SEPULVEDA BLVD.
LOS ANGELES, CA 90009
ATTN ROBT. WEIR, DEPT. 93-9
ATTN TECH LIB

GENERAL DYNAMICS CORP.
ELECTRO-DYNAMIC DIVISION
POMONA OPERATION
PO BOX 2507
POMONA, CA 91766
ATTN TECH LIB

GENERAL DYNAMICS CORP.
ELECTRONICS DIVISION
P.O. BOX 81127
SAN DIEGO, CA 92138
ATTN TECH LIB

GENERAL ELECTRIC COMPANY
SPACE DIVISION
VALLEY FORGE SPACE CENTER
GODDARD BLVD KING OF PRUSSIA
P.O. BOX 8555
PHILADELPHIA, PA 19101
ATTN JAMES P. SPRATT
ATTN DANIEL EDELMAN
ATTN DANTE M. TASCA
ATTN JOHN R. GREENBAUM
ATTN LARRY I. CHASEN
ATTN JOSEPH C. PEDEN, CCF 8301
ATTN TECH INFO CENTER

GENERAL ELECTRIC COMPANY
RE-ENTRY & ENVIRONMENTAL SYSTEMS DIV
PO BOX 7722
3198 CHESTNUT STREET
PHILADELPHIA, PA 19101
ATTN TECH LIB

GENERAL ELECTRIC COMPANY
ORDNANCE SYSTEMS
100 PLASTICS AVENUE
PITTSFIELD, MA 01201
ATTN JOSEPH J. REIDL

GENERAL ELECTRIC COMPANY
WASHINGTON OFFICE
AEROSPACE GRP STRAT PLANNING & PRGMS OPS
777 14TH STREET NW, WYATT BUILDING
WASHINGTON, DC 20005
ATTN DASIAC, WILLIAM ALFONTE

GENERAL ELECTRIC COMPANY
TEMPO-CENTER FOR ADVANCED STUDIES
816 STATE STREET (PO DRAWER QQ)
SANTA BARBARA, CA 93102
ATTN DASIAC
ATTN ROYDEN R. RUTHERFORD

GENERAL ELECTRIC COMPANY
PO BOX 1122
SYRACUSE, NY 13201
ATTN TECH LIB
ATTN CSP 6-7, RICHARD C. FRIES

GENERAL ELECTRIC COMPANY
AIRCRAFT ENGINE GROUP
EVENDALE PLANT
CINCINNATI, OH 45215
ATTN TECH LIB
ATTN JOHN A. ELLERHORST, E2

GENERAL ELECTRIC COMPANY
AEROSPACE ELECTRONICS SYSTEMS
FRENCH ROAD
UTICA, NY 13503
ATTN TECH LIB
ATTN CHARLES M. HEWISON, DROP 624
ATTN W. J. PATTERSON, DROP 233

GENERAL ELECTRIC COMPANY
PO BOX 5000
BINGHAMTON, NY 13302
ATTN TECH LIB
ATTN DIVID W. PEPIN, DROP 160

GENERAL RESEARCH CORPORATION
P.O. BOX 3587
SANTA BARBARA, CA 93105
ATTN TECH INFO OFFICE
ATTN JOHN ISE, JR.

DISTRIBUTION (CONT'D)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF RESEARCH ADMINISTRATION
ATLANTA, GA 30332
ATTN RES & SEC COORDINATOR
FOR MR. HUGH DENNY

GRUMMAN AEROSPACE CORPORATION
SOUTH OYSTER BAY ROAD
BETHPAGE, NY 11714
ATTN JERRY ROGERS, DEPT 533
ATTN TECHNICAL LIBRARY

GTE SYLVANIA, INC.
ELECTRONICS SYSTEMS GRP-EASTERN DIV
77 A STREET
NEEDHAM, MA 02194
ATTN CHARLES A. THORNHILL, LIBRARIAN
ATTN LEONARD L. BLAISDELL
ATTN JAMES A. WALDON

GTE SYLVANIA, INC.
189 B STREET
NEEDHAM HEIGHTS, MA 02194
ATTN DAVID P. FLOOD
ATTN CHARLES H. RAMSBOTTOM
ATTN A S M DEPT, S. E. PERLMAN
ATTN COMM SYST DIV, EMIL P. MOTCHOK
ATTN HERBERT A. ULLMAN
ATTN H & V GROUP, MARIO A. NUREFORA

HARRIS CORPORATION
HARRIS SEMICONDUCTOR DIVISION
P.O. BOX 883
MELBOURNE, FL 32901
ATTN C. F. DAVIS, MS 17-220
ATTN WAYNE E. ABARE, MS 16-111
ATTN T. CLARK, MS 4040
ATTN TECH LIB
ATTN CHARLES DENTON, JR., MS 1-500

HAZELTINE CORPORATION
PULASKI ROAD
GREEN LAWN, NY 11740
ATTN TECH INFO CTR, M. WAITE

HERCULES, INC.
BACCHUS PLANT
P.O. BOX 98
MAGNA, UT 84044
ATTN TECH LIB

HONEYWELL INCORPORATED
GOVERNMENT AND AERONAUTICAL
PRODUCTS DIVISION
1625 ZARTHAN AVENUE
MINNEAPOLIS, MN 55416
ATTN TECH LIB
ATTN RONALD R. JOHNSON, A1622

HONEYWELL INCORPORATED
AEROSPACE DIVISION
13350 US HIGHWAY 19
ST. PETERSBURG, FL 33733
ATTN TECHNICAL LIBRARY
ATTN HARRISON H. NOBLE, MS 725-5A

HONEYWELL INCORPORATED
RADIATION CENTER
2 FORBES ROAD
LEXINGTON, MA 02173
ATTN TECHNICAL LIBRARY

HUGHES AIRÇRAFT COMPANY
CENTINELLA AVENUE & TEALE STREETS
CULVER CITY, CA 90230
ATTN M.S. D157, KEN WALKER
ATTN TECHNICAL LIB
ATTN B. W. CAMPBELL, M.S. 6-E110
ATTN JOHN B. SINGLETARY, MS 6-D133

HUGHES AIRCRAFT COMPANY
GROUND SYSTEMS GROUP
1901 WEST MALVERN AVENUE
FULLERTON, CA 92634
ATTN LIBRARY, MS C-222

HUGHES AIRCRAFT COMPANY
SPACE SYSTEMS DIVISION
P.O. BOX 92919
LOS ANGELES, CA 90009
ATTN TECHNICAL LIB
ATTN WILLIAM W. SCOTT, MS A1080
ATTN HAROLD A. BOYTE, MS A1080
ATTN EDWARD C. SMITH, MS A620

IBM CORPORATION
ROUTE 17C
OWEGO, NY 13827
ATTN TECHNICAL LIBRARY
ATTN FRANK FRANKOVSKY

IIT RESEARCH INSTITUTE
ELECTROMAGNETIC COMPATABILITY
ANALYSIS CENTER
NORTH SEVERN
ANNAPOLIS, MD 21402
ATTN TECH LIB
ATTN ACOAT

IIT RESEARCH INSTITUTE
10 WEST 35TH STREET
CHICAGO, IL 60616
ATTN TECHNICAL LIBRARY
ATTN IRVING N. MINDE

INSTITUTE FOR DEFENSE ANALYSES
400 ARMY-NAVY DRIVE
ARLINGTON, VA 22202
ATTN IO, LIBRARIAN, RUTH S. SMITH

INTERNATIONAL TELEPHONE AND
TELEGRAPH CORPORATION
500 WASHINGTON AVENUE
NUTLEY, NJ 07110
ATTN TECHNICAL LIBRARY
ATTN DEF SP GROUP, J. GULACK
ATTN ALEXANDER I. RICHARDSON

ION PHYSICS CORPORATION
SOUTH BEDFORD STREET
BURLINGTON, MA 01803
ATTN TECH LIB

IRT CORPORATION
7650 CONVOY COURT
SAN DIEGO, CA 92111
ATTN R. L. MERTZ
ATTN ERIC P. WENAAS
ATTN MDC
ATTN TECHNICAL LIBRARY
ATTN RALPH H. STAHL

JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
JOHNS HOPKINS ROAD
LAUREL, MD 20810
ATTN TECH LIB

KAMAN SCIENCES CORPORATION
PO BOX 7463
COLORADO SPRINGS, CO 80933
ATTN LIBRARY
ATTN DONALD H. BRYCE
ATTN ALBERT P. BRIDGES
ATTN W. FOSTER RICH
ATTN WALTER E. WARE

LITTON SYSTEMS, INC.
DATA SYSTEMS DIVISION
8000 WOODLEY AVENUE
VAN NUYS, CA 91406
ATTN TECH LIB

LITTON SYSTEMS, INC.
GUIDANCE & CONTROL SYSTEMS DIVISION
5500 CANOGA AVENUE
WOODLAND HILLS, CA 91364
ATTN VAL J. ASHBY, MS 67
ATTN TECHNICAL LIBRARY
ATTN JOHN P. RETZLER

LITTON SYSTEMS, INC.
AMECOM DIVISION
5115 CALVERT ROAD
COLLEGE PARK, MD 20740
ATTN TECH LIB

LOCKHEED MISSILES AND SPACE COMPANY, INC.
P.O. BOX 504
SUNNYVALE, CA 94088
ATTN G. F. HEATH, D/81-14
ATTN D. M. TELLER, EPT 81-01
ATTN BENJAMIN T. KIMURA, DEPT 81-14,
BLDG 154
ATTN H. SCHNEEMANN ORG 81-64
ATTN KEVIN MCCARTHY 0-85-71,
ATTN EDWIN A. SMITH, DEPT 85-85
ATTN TECHNICAL LIBRARY
ATTN L-365 DEPT 81-20
ATTN PHILIP J. HART, DEPT 81-14

LOCKHEED MISSILES AND SPACE COMPANY
3251 HANOVER STREET
PALO ALTO, CA 94304
ATTN TECH INFO CTR, D/COLL

LTV AEROSPACE CORPORATION
VOUGHT SYSTEMS DIVISION
P.O. BOX 6267
DALLAS, TX 75222
ATTN TECHNICAL DATA CENTER

LTV AEROSPACE CORPORATION
MICHIGAN DIVISION
P.O. BOX 909
WARREN, MI 48090
ATTN TECH LIB

M.I.T. LINCOLN LABORATORY
P.O. BOX 73
LEXINGTON, MA 02173
ATTN LEONA LOUGHLIN, LIBRARIAN

MARTIN MARIETTA AEROSPACE
ORLANDO DIVISION
P.O. BOX 5837
ORLANDO, FL 32805
ATTN MONA C. GRIFFITH, LIB MP-30
ATTN WILLIAM W. MRAS, MP-413
ATTN JACK M. ASHFORD, MP-537

MARTIN MARIETTA CORPORATION
DENVER DIVISION
PO BOX 179
DENVER, CO 80201
ATTN RESEARCH LIB, 6617, J. R. MCKEE
ATTN PAUL G. KASE, MAIL 8203
ATTN BEN T. GRAHAM, MS PO-454

MAXWELL LABORATORIES, INC.
9244 BALBOA AVENUE
SAN DIEGO, CA 92123
ATTN TECH LIB
ATTN VICTOR FARGO

MCDONNELL DOUGLAS CORPORATION
POST OFFICE BOX 516
ST. LOUIS, MO 63166
ATTN TOM ENDER
ATTN TECHNICAL LIBRARY

MCDONNELL DOUGLAS CORPORATION
5301 BOLSA AVENUE
HUNTINGTON BEACH, CA 92647
ATTN W. R. SPARK, MS 13-3
ATTN PAUL H. DUNCAN, JR.
ATTN STANLEY SCHNEIDER
ATTN A. P. VENDITT, MS 11-1
ATTN TECH LIBRARY SERVICES

MCDONNELL DOUGLAS CORPORATION
PO BOX 1850
ALBUQUERQUE, NM 87103
ATTN THOMAS J. LUNDREGAN

MISSION RESEARCH CORPORATION
735 STATE STREET
SANTA BARBARA, CA 93101
ATTN TECH LIB
ATTN CONRAD L. LONGMIRE
ATTN WILLIAM C. HART
ATTN DANIEL F. HIGGINS

MISSION RESEARCH CORPORATION
P.O. BOX 8693, STATION C
ALBUQUERQUE, NM 87108
ATTN LARRY D. SCOTT
ATTN TECH LIB
ATTN DAVID E. MEREWETHER

MITRE CORPORATION, THE
ROUTE 62 AND MIDDLESEX TURNPIKE
P.O. BOX 208
BEDFORD, MA 01730
ATTN LOUIS BRICKMORE
ATTN LIBRARY
ATTN THEODORE JARVIS
ATTN M. F. FITZGERALD

NATIONAL ACADEMY OF SCIENCES
2101 CONSTITUTION AVE, NW
WASHINGTON,DC 20418
ATTN DR. R. S. SHANE,
NAT MATERIALS ADVISORY BO

NORTHROP CORPORATION
ELECTRONIC DIVISION
1 RESEARCH PARK
PALOS VERDES PENINSULA, CA 92074
ATTN TECH LIB
ATTN JOHN M. REYNOLDS
ATTN VINCENT R. DEMARTINO

NORTHROP CORPORATION
NORTHROP RESEARCH AND TECHNOLOGY CENTER
3401 WEST BROADWAY
HAWTHORNE, CA 92050
ATTN LIBRARY
ATTN DAVID N. POCOCK

NORTHROP CORPORATION
ELECTRONIC DIVISION
2301 WEST 120TH STREET
HAWTHORNE, CA 90250
ATTN TECH LIB

PALISADES INST FOR RSCH SERVICES INC.
201 VARICK STREET
NEW YORK, NY 10014
ATTN RECORDS SUPERVISOR

PERKIN-ELMER CORPORATION
MAIN AVENUE
NORWALK, CT 06852
ATTN TECH LIB

PHYSICS INTERNATIONAL COMPANY
2700 MERCED STREET
SAN LEANDRO, CA 94577
ATTN TECH LIB
ATTN JOHN. HUNTINGTON

PROCEDYNE CORPORATION
221 SOMERSET STREET
NEW BRUNSWICK, NJ 08903
ATTN PETER HOROWITZ
ATTN TECH LIB

PULSAR ASSOCIATES, INC.
7911 HERSCHEL AVENUE
LA JOLLA, CA 92037
ATTN CARLETON JONES

R & D ASSOCIATES
P.O. BOX 9695
MARINA DEL REY, CA 90291
ATTN TECHNICAL LIBRARY
ATTN S. CLAY ROGERS
ATTN WILLIAM R. GRAHAM, JR.
ATTN CHARLES MO
ATTN WILLIAM J. KARZAS
ATTN RICHARD R. SCHAEFER
ATTN LEONARD SCHLESSINGER
ATTN GERARD K. SCHLEGEL

RAND CORPORATION, THE
1700 MAIN STREET
SANTA MONICA, CA 90406
ATTN TECHNICAL LIBRARY
ATTN DR. CULLEN CRAIN

RAYTHEON COMPANY
HARTWELL ROAD
BEDFORD, MA 01730
ATTN LIBRARY
ATTN GAJANAN H. JOSHI,
RADAR SYS LAB

RATHEON COMPANY
528 BOSTON POST ROAD
SUDBURY, MA 01776
ATTN HAROLD L. FLESCHER
ATTN JAMES R. WECKBACK
ATTN TECH LIB

RCA CORPORATION
GOVERNMENT & COMMERCIAL SYSTEMS
ASTRO ELECTRONICS DIVISION
PO BOX 800, LOCUST CORNER
PRINCETON, NJ 08540
ATTN TECH LIB
ATTN GEORGE J. BRUCKER

RCA CORPORATION
GOVERNMENT & COMMERCIAL SYSTEMS
MISSILE & SURFACE RADAR DIVISION
MARNE HIGHWAY & BORTON LANDING RD
MOORESTOWN, NJ 08057
ATTN TECHNICAL LIBRARY
ATTN ANDREW L. WARREN

RCA CORPORATION
CAMDEN COMPLEX
FRONT & COOPER STREETS
CAMDEN, NJ 08012
ATTN TECH LIB
ATTN E. VAN KEUREN, 13-5-2

ROCKWELL INTERNATIONAL CORPORATION
3370 MIROLOMA AVENUE
ANAHEIM, CA 92803
ATTN K. F. HULL
ATTN TECHNICAL LIBRARY
ATTN JAMES E. BELL, HA10
ATTN L. APODACA, FA53
ATTN DONALD J. STEVENS, FA70
ATTN N. J. RUDIE, FA53

ROCKWELL INTERNATIONAL CORPORATION
SPACE DIVISION
12214 SOUTH LAKEWOOD BOULEVARD
DOWNEY, CA 90241
ATTN TIC D/41-092 AJ01

ROCKWELL INTERNATIONAL CORPORATION
5701 WEST IMPERIAL HIGHWAY
LOS ANGELES, CA 90009
ATTN T. B. YATES

SANDERS ASSOCIATES, INC.
95 CANAL STREET
NASHUA, NH 03060
ATTN 1-6270, R. G. DESPATHY SR., P.E.
ATTN TECH LIB
ATTN M. L. AITEL NCA 1-3236

SCIENCE APPLICATIONS, INC.
PO BOX 277
BERKELEY, CA 94701
ATTN FREDERECK M. TESCHE

SCIENCE APPLICATIONS, INC.
1651 OLD MEADOW ROAD
MCLEAN, VA 22101
ATTN WILLIAM L. CHADSEY

SCIENCE APPLICATIONS, INC.
P.O. BOX 2351
LA JOLLA, CA 92037
ATTN TECHNICAL LIBRARY
ATTN LEWIS M. LINSON

SCIENCE APPLICATIONS, INC.
HUNTSVILLE DIVISION
2109 W. CLINTON AVENUE
SUITE 700
HUNTSVILLE, AL 35805
ATTN NOEL R. BYRN
ATTN TECH LIB

SCIENCE APPLICATIONS, INC.
PO BOX 3507
ALBUQUERQUE, NM 87110
ATTN RICHARD L. KNIGHT
ATTN JAMES R. HILL
ATTN R. PARKINSON

SIMULATION PHYSICS, INC.
41 "B" STREET
BURLINGTON, MA 01803
ATTN JOHN R. UGLUM

SINGER COMPANY, THE
1150 MC BRIDE AVENUE
LITTLE FALLS, NJ 07424
ATTN TECH LIB
ATTN IRWIN GOLDMAN, ENG MANAGEMENT

SPERRY MICROWAVE ELECTRONICS DIV
SPERRY RAND CORPORATION
PO BOX 4648
CLEARWATER, FL 33518
ATTN TECH LIB

SPERRY FLIGHT SYSTEMS DIVISION
SPERRY RAND CORPORATION
PO BOX 21111
PHOENIX, AZ 85036
ATTN D. J. KEATING
ATTN TECH LIB
ATTN D. ANDREW SCHOW

SPERRY RAND CORPORATION
UNIVAC DIVISION
DEFENSE SYSTEMS DIVISION
P.O. BOX 3525 MAIL STATION 1931
ST. PAUL, MN 55101
ATTN TECH LIB

SPERRY RAND CORPORATION
SPERRY DIVISION
SPERRY GYROSCOPE DIVISION
SPERRY MANAGEMENT DIVISION
MARCUS AVENUE
GREAT NECK, NY 11020
ATTN PAUL MARRAFFINO
ATTN CHARLES L. CRAIG EV
ATTN TECH LIB

STANFORD RESEARCH INSTITUTE
333 RAVENSWOOD AVENUE
MENLOW PARK, CA 94025
ATTN MR. PHILIP DOLAN
ATTN GEORGE CARPENTER
ATTN ARTHUR LEE WHITSON
ATTN SRI LIBRARY, ROOM G021

STANFORD RESEARCH INSTITUTE
306 WYNN DRIVE, NW
HUNTSVILLE, AL 35805
ATTN MACPHERSON MORGAN
ATTN TECH LIB

SUNDSTRAND CORPORATION
4751 HARRISON AVENUE
ROCKFORD, IL 61101
ATTN CURTIS B. WHITE

SYSTEMS, SCIENCE AND SOFTWARE
PO BOX 4803
HAYWARD, CA 94540
ATTN TECH LIB

SYSTEMS, SCIENCE AND SOFTWARE, INC.
PO BOX 1620
LA JOLLA, CA 92038
ATTN TECHNICAL LIBRARY

SYSTRON-DONNER CORPORATION
1090 SAN MIGUEL ROAD
CONCORD, CA 94518
ATTN TECH LIB

TEXAS INSTRUMENTS, INC.
PO BOX 6015
DALLAS, TX 75222
ATTN TECH LIB
ATTN DONALD J. MANUS, MS 72

THE SINGER COMPANY (DATA SYSTEMS)
150 TOTOWA ROAD
WAYNE, NJ 07470
ATTN TECH INFO CENTER

TRW SEMICONDUCTORS
DIVISION OF TRW, INC.
14520 AVIATION BLVD.
LAWNDALE, CA 90260
ATTN TECH LIB
ATTN RONALD N. CLARKE

TRW SYSTEMS GROUP
ONE SPACE PARK
REDONDO BEACH, CA 90278
ATTN TECH INFO CENTER/S-1930
ATTN A. M. LIEBSCHUTZ R1-1162
ATTN ROBERT M. WEBB, MS R1-1150
ATTN AARON H. NAREVSKY, R1-2144
ATTN WILLIAM H. ROBINETTE, JR.
ATTN BENJAMIN SUSSHOLTZ
ATTN RICHARD H. KINGSLAND, R1-2154
ATTN JERRY I. LUBELL
ATTN FRED N. HOLMQUIST, MS R1-2028
ATTN LILLIAN D. SINGLETARY, R1/1070

TRW SYSTEMS GROUP
SAN BERNARDINO OPERATIONS
PO BOX 1310
SAN BERNARDINO, CA 92402
ATTN JOHN E. DAHNKE
ATTN H. S. NENSEN

TRW SYSTEMS GROUP
PO BOX 368
CLEARFIELD, UT 84015
ATTN TECH LIB

UNITED TECHNOLOGIES CORPORATION
HAMILTON STANDARD DIVISION
BRADLEY INTERNATIONAL AIRPORT
WINDSOR LOCKS, CT 06069
ATTN TECH LIB
ATTN RAYMOND G. GIGUERE

UNITED TECHNOLOGIES CORPORATION
NORDEN DIVISION
HELEN STREET
NORWALK, CT 06851
ATTN TECH LIB

VAN LINT, VICTOR A. J. (CONSULTANT)
7650 CONVOY COURT
SAN DIEGO, CA 92111
ATTN V. A. J VAN LINT

VARIAN ASSOCIATES
611 HANSEN WAY
PALO ALTO, CA 94303
ATTN TECH LIB
ATTN A-109, HOWARD R. JORY

WESTINGHOUSE ELECTRIC CORPORATION
ASTRONUCLEAR LABORATORY
PO BOX 10864
PITTSBURGH, PA 15236
ATTN TECH LIB

WESTINGHOUSE ELECTRIC CORPORATION
DEFENSE AND ELECTRONIC SYSTEMS CENTER
P.O. BOX 1693
FRIENDSHIP INTERNATIONAL AIRPORT
BALTIMORE, MD 21203
ATTN HENRY P. KALAPACA, MS 3525
ATTN TECH LIB

WESTINGHOUSE ELECTRIC CORPORATION
RESEARCH AND DEVELOPMENT CENTER
1310 BEULAH ROAD, CHURCHILL BOROUGH
PITTSBURGH, PA 15235
ATTN TECH LIB

COMMANDER
HARRY DIAMOND LABORATORIES
2800 POWDER MILL RD
ADELPHI, MD 20783
ATTN MCGREGOR, THOMAS, COL, COMMANDING OFFICER/FLYER, I.N./LANDIS, P.E./ SOMMER, H./CONRAD, E.E.
ATTN CARTER, W.W., DR., ACTING TECHNICAL DIRECTOR/MARCUS, S.M.
ATTN KIMMEL, S., PIO
ATTN CHIEF, 0021
ATTN CHIEF, 0022
ATTN CHIEF, LAB 100
ATTN CHIEF, LAB 200
ATTN CHIEF, LAB 300
ATTN CHIEF, LAB 400
ATTN CHIEF, LAB 500
ATTN CHIEF, LAB 600
ATTN CHIEF, DIV 700
ATTN CHIEF, DIV 800
ATTN CHIEF, LAB 900
ATTN CHIEF, LAB 1000
ATTN RECORD COPY, BR 041
ATTN HDL LIBRARY (3 COPIES)
ATTN CHAIRMAN, EDITORIAL COMMITTEE (4 COPIES)
ATTN CHIEF, 047
ATTN TECH REPORTS, 013
ATTN PATENT LAW BRANCH, 071
ATTN MCLAUGHLIN, P.W., 741
ATTN ROSADO, J. A., LAB 200
ATTN MCCOSKEY, R. E., LAB 200
ATTN THOMPKINS, J. E., LAB 200
ATTN BELFUSS, N. W., 240
ATTN SWETON, J. F., 1000
ATTN WONG, R., 1000
ATTN MILETTA, J. R., 240
ATTN WIMENITZ, F. N., 0024
ATTN WYATT, W. T., JR., 1000
ATTN KLEBERS, J., 1000
ATTN BOMBARDT, J., 1000
ATTN GRAY, R. F., 1000 (50 COPIES)

DEPARTMENT OF THE ARMY
HARRY DIAMOND LABORATORIES
2800 POWDER MILL RD
ADELPHI, MD 20783

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

AN EQUAL OPPORTUNITY EMPLOYER

POSTAGE AND FEES PAID
DEPARTMENT OF THE ARMY
DOD 314

THIRD CLASS

COMMANDER
USA ARMAMENTS COMMAND
ROCK ISLAND, IL 61201
ATTN AMSAR-ASF, FUZE DIV

VANGUARD OF FREEDOM
BICENTENNIAL 1775-1975
UNITED STATES ARMY